Department of Energy
Oak Ridge Operations
Weldon Spring Site
Remedial Action Project Office
Route 2, Highway 94 South
St. Charles, Missouri 63303

January 17, 1989

ADDRESSEES

HYDROGEOLOGIC INVESTIGATIONS SAMPLING PLAN

Enclosed is Revision 0 of the "Hydrogeologic Investigations Sampling Plan" for the Weldon Spring Site. This plan has been revised to address comments received from U. S. Environmental Protection Agency and the Missouri Department of Natural Resources as indicated in the "Responsiveness Summary", also enclosed.

Sincerely,

R. R. Nelson

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Enclosures:
As stated

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United States Department Of Energy

HYDROGEOLOGIC INVESTIGATIONS SAMPLING PLAN

REV. 0

NOVEMBER, 1988

WELDON SPRING SITE REMEDIAL ACTION PROJECT

HYDROGEOLOGIC INVESTIGATION

SAMPLING PLAN

PREPARED FOR:

U.S. DEPARTMENT OF ENERGY

OAK RIDGE OPERATIONS OFFICE

CONTRACT NO. DE-AC05-86OR21548

PREPARED BY:

MK-FERGUSON COMPANY

AND

JACOBS ENGINEERING GROUP, INC.

ROUTE 2, HIGHWAY 94 SOUTH

ST. CHARLES, MISSOURI 63303

REVISION 0

NOVEMBER 1988

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1.0 PROJECT DESCRIPTION

1.1 INTRODUCTION

The goal of this sampling plan is to identify and develop specific plans for those investigative actions necessary to: (1) characterize the hydrologic regime; (2) define the extent and impact of contamination; and (3) predict future contaminant migration for the Weldon Spring Site (WSS) and vicinity. The plan is part of the Weldon Spring Site Remedial Action Project (WSSRAP) sponsored by the U.S. Department of Energy (DOE) and has been developed in accordance with U.S. EPA Remedial Investigation (RI) and Data Quality Objective (DQO) guidelines. The plan consists of a sequence of activities including the evaluation of data, development of a conceptual model, identification of data uses and needs, and the design and implementation of a data collection program.

Data will be obtained to: (1) confirm the presence or absence of contaminants; (2) define contaminant sources and modes of transport; (3) delineate extent of contaminant migration and predict future migration; and (4) provide information to support the evaluation and selection of remedial actions.

This sampling plan is intended to supplement the Quality Assurance Program Plan (QAPP). It describes objectives, work tasks, quality assurance/quality control (QA/QC) procedures, and the level of effort required for site characterization and to support a feasibility study. Data developed through this sampling plan will also be used in the risk assessment evaluation.

The WSSRAP consists of remedial activities at the WSS, vicinity properties, and quarry. This sampling plan addresses activities required for the hydrogeologic investigation of the WSS. The quarry and vicinity properties associated with the quarry will be addressed, in detail, in a separate site characterization report.

A comprehensive approach is planned for hydrogeological characterization. This includes monitoring well installation, water sampling and analysis, karst hydrologic studies, unsaturated zone studies, aquifer testing, regional studies, and groundwater modeling studies. Modeling will be performed in cooperation with the Missouri Department of Natural Resources, the U.S. Geological Survey, and the University of Missouri, Rolla.

1.2 REVIEW AND ASSESSMENT OF EXISTING DATA

Numerous studies have been performed at the WSS and vicinity. This section addresses site history and assesses those studies directly related to the WSS. The completeness, representativeness, and accuracy of collected data are briefly evaluated.

Maps, sections, and data presented in this section are, for the most part, based on information acquired prior to current (1988) characterization activities. Much of this information is not site-specific; therefore figures, tables, and data presented in this section will be modified as additional data are collected.

1.2.1 Site Background and Investigations

The WSS is located along Missouri Highway 94 in western St. Charles County, Missouri, approximately 30 miles west of St. Louis, and 2 miles southwest of the junction of U.S. Highway 40/61 and State Highway 94. The general location of the WSS is shown on Figure 1-1. An enlarged view of the site is shown on Figure 1-2. Figure 1-3 (in pocket) presents a topographic map of the Weldon Spring Site area.

The WSS described in this sampling plan consists of two adjoining

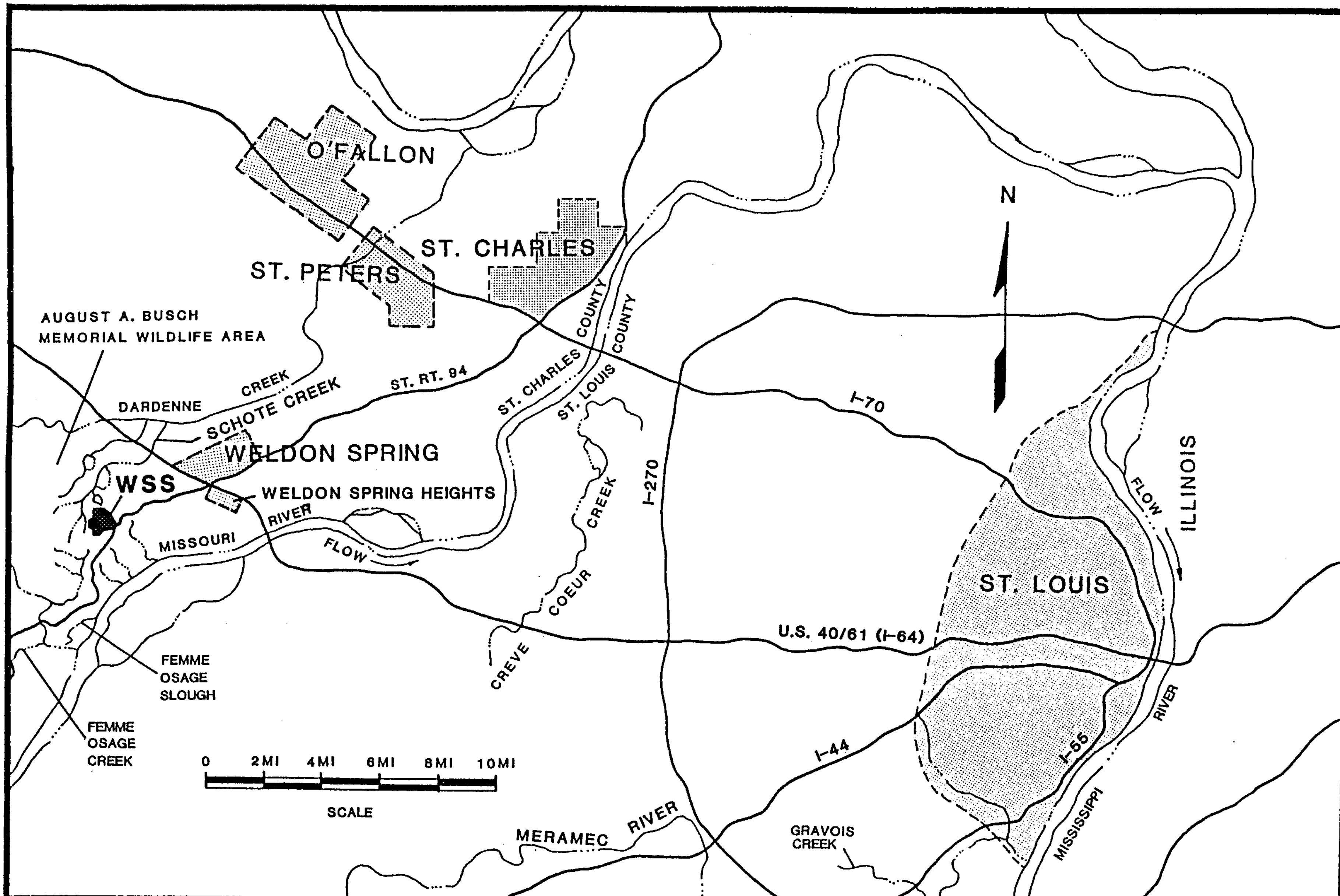

FIGURE 1-1

LOCATION OF THE WELDON SPRING SITE

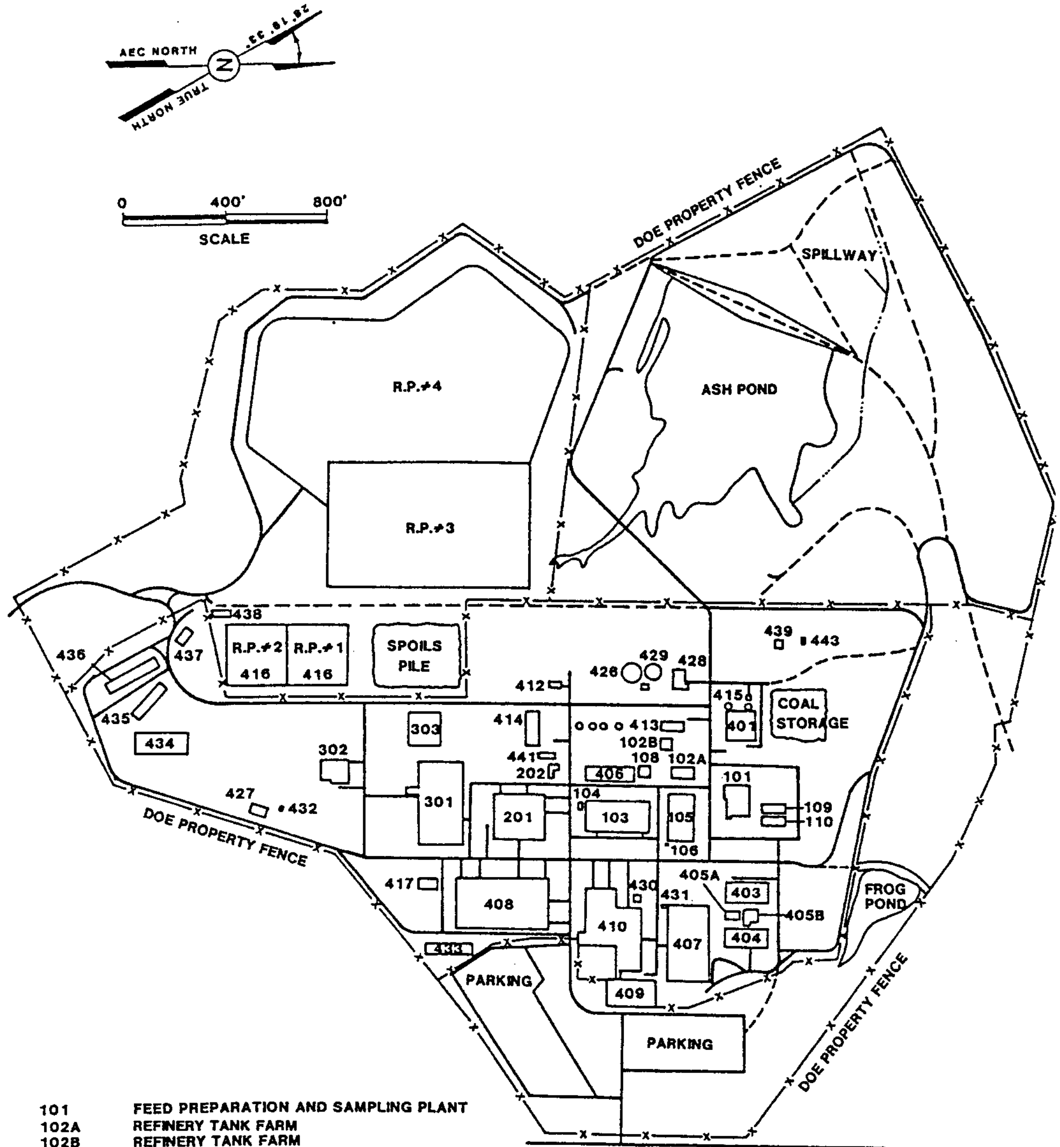

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FIGURE 1-2

WELDON SPRING CHEMICAL PLANT AND RAFFINATE PITS (MAJOR BUILDINGS AND FEATURES) areas: the Weldon Spring Raffinate Pits (WSRP) on the west, and the Weldon Spring Chemical Plant (WSCP) on the east, encompassing 51 and 166 acres respectively (MK-Ferguson -- MKF, 1987b). The 166-acre WSCP consists of 13 major buildings and approximately 30 support structures. The 51-acre WSRP area, located in the western portion of the site, contains four surface impoundments (raffinate pits) covering approximately 26 acres. These pits contain the residues of uranium and thorium processing from the former feed materials plant (MKF, 1987b).

Activities at the WSS have been varied. The U.S. Department of the Army (DOA) and predecessor agencies to the U.S. Department of Energy (DOE) have actively participated in developments at the site. A brief summary of these site activities is presented below.

The DOA acquired the site and surrounding areas, totaling more than 17,000 acres, in 1941 for an ordnance works to produce explosives. From 1941 to 1944, trinitrotoluene (TNT) and dinitrotoluene (DNT) were manufactured on the DOA property. Fishel and Williams (1944) reported the presence of red waste waters which were contaminating surface and groundwater during this period. At the end of World War II, the manufacturing operation was shut down and processing structures were abandoned. The Army conducted additional decontamination operations in 1946, destroying over 200 buildings and burning approximately 90 tons of nitroaromatics and residues (MKF, 1987). The ordnance works property was declared surplus in 1946, and during the next three years about 15,000 acres were transferred to other parties. By the end of 1949 only about 2,000 acres remained under the jurisdiction of the U.S. Army.

In 1956 the U.S. Army transferred about 205 acres to the U.S. Atomic Energy Commission (AEC) for the construction of a uranium feed materials plant on the Army's previous manufacturing site. The remaining TNT-processing equipment and structures were demolished and removed to the Weldon Spring Quarry prior to construction of the AEC plant.

The AEC plant began operation in 1957. The plant converted impure uranium concentrates to pure uranium salts and metal. From 1958 to 1964 the plant operated at several times design capacity, overtaxing the facility and its waste disposal facilities, and resulting in radiological contamination of numerous buildings and land in the vicinity of the plant. Raffinate pits were excavated in 1958, 1959, and 1964 for disposal of wastes from processing uranium and thorium concentrates. Thorium oxide was processed at the plant during 1965 and 1966, with wastes being discharged to Raffinate Pit No. 4. Shutdown of the plant was initiated at the end of 1966; drums and trash were dumped into Raffinate Pit No. 4 during close-down operations.

In 1967, 166 acres of the plant site were transferred back to the Army for the intended manufacture of "Agent Orange." Some equipment removal and decontamination was accomplished for that purpose. The project was cancelled, however, in 1969. The U.S. Army Corps of Engineers took custody of the plant in 1969 after additional cleanup and shutdown work.

In 1975, the Army assessed the environmental conditions at the site and indicated that the site could not be released to unrestricted use without decontamination of the land and buildings. A similar conclusion was reached in a report to the U.S. Energy Research and Development Administration (ERDA) and recommendations were made for collection of additional data (Kleeschulte and Emmett, 1986).

The WSS remained under Army control until 1985 when custody was transferred to DOE (MKF, 1987b). Numerous efforts have been undertaken in recent years to assess the environmental problems associated with the WSS and to develop plans for remediation.

Studies providing site-specific geologic, hydrologic, and environmental information have been performed by several individuals and groups. Each investigation is briefly described in Section 5, References. In addition to these investigations, a number of environmental monitoring activities have been accomplished during the last 30 years. Data from some of these activities are included in reports by Mallinckrodt Chemical Works (1959-1965), DOA (1977-1985), Bechtel National, Inc. (BNI) (1983-1984), National Lead Company of Ohio (1981-1982), Shell Engineering (1983-1985), and MKF (1986-1987). These studies are evaluated and summarized in following sections.

1.2.2 Climate

The climate in the WSS area is continental, with moderately cold winters and warm summers. Alternating warm/cold, wet/dry air masses converge and pass eastward through the area almost daily (BNI, 1986b). Normal annual precipitation in the area is approximately 37 inches with the heaviest rainfall occurring in spring and early summer (DOE, 1987). The average temperature is $13^{\circ}C$ ($56^{\circ}F$), with the average daily minimum being $7^{\circ}C$ ($45^{\circ}F$) and the average daily maximum being $19^{\circ}C$ ($66^{\circ}F$). Wind speeds and directions recorded at the WSS during 1985 are summarized in Figure 1-4. Prevailing winds in the vicinity of the WSS are from the south during the summer and fall. Wind speeds during these months average 8.7 mph. Winds during the winter months are from the northwest and west-northwest, averaging 11 mph (MKF, 1987b).

The variability of the climate is demonstrated by records for the state. The range in temperatures for the 1888-1949 period was from a $-40^{\circ}F$ to $118^{\circ}F$ and the range in annual precipitation was from less than 26 inches to more than 55 inches (Roberts, 1951). Summer rains frequently occur as thunderstorms, occasionally with hail and high winds. Locally, rainfalls can be very heavy, with 10 inches having been recorded

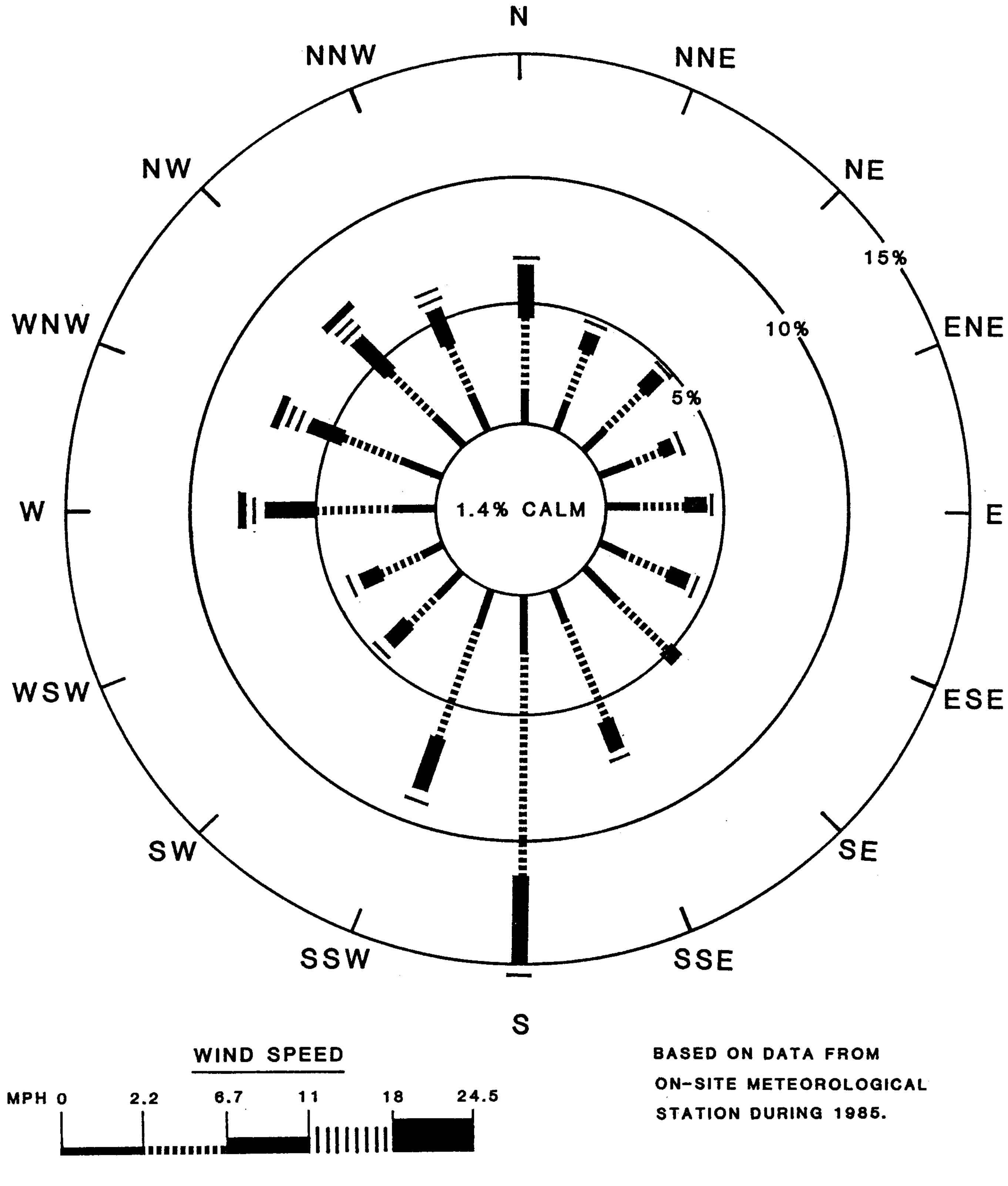


FIGURE 1-4

ANNUAL WIND ROSE FOR THE W S S , 1985.

in a 24-hour period. The three winter months are the driest, with the average precipitation totaling about 6 inches. The three spring months are typically the wettest with the average total approximately 12 inches (Ficker, 1981). Tornadoes occur in the St. Louis area once or twice per year, and occur most often in April and May (Sci. Appl., 1979).

Site-specific climatologic data are generally limited to the period beginning in April 1983 (BNI, 1986a; MKF, 1986).

1.2.3 Surface Features

The site is located on the drainage divide between the Mississippi and Missouri rivers. Drainage from the northern and western portions of the WSS trends northward to tributaries of Schote Creek, a tributary ultimately draining to the Mississippi River. The southeastern portion of the site drains generally southward to unnamed tributaries which flow to the Missouri River. Elevations on the site range from approximately 608 feet near the northern edge to approximately 672 feet near the southern edge. Land surface slopes are generally gentle except in the vicinity of embankments or levees for the raffinate pits and Ash Pond. There are no natural drainage channels traversing the site, though remnants of a channel through the Ash Pond area are present.

Figure 1-2 illustrates the current configuration of facilities on the site. In addition to the readily apparent ponds, pits, and buildings, there are numerous other features including drainage ditches and other topographic features that can influence the movement of contaminants. Some of the surface features are associated with man-made subsurface features, such as sewer lines, which can also influence the movement of contaminants. The changes that have taken place at the WSS over the years have added to the complexity of the site.

There are several localized depressions or ponding areas which have received natural runoff or process wastes over the years. These include the raffinate pits, Frog Pond, Ash Pond, the Imhoff tank (former wastewater treatment) and the Southeast Drainage Easement. Raffinate Pits 1, 2, 3, and 4 were constructed in the late 1950s and early 1960s for receiving process wastewaters. In addition to receiving process wastes, they have received precipitation and runoff. Also the topography of the raffinate pits influences the direction and rate of surface runoff originating or flowing in their vicinity. Frog Pond is a settling basin located near the east edge of the site. It receives runoff from the eastern portion of the site. Ash Pond is a major feature near the north edge of the site and receives runoff from the northern portion of the site. When runoff has accumulated sufficiently in Ash Pond, overflow occurs through its spillway with subsequent discharge from the site. The Ash Pond received ash slurry from the steam generating plant (Building 401). Another feature that influences the movement of contaminants is the Southeast Drainage Easement. Historically, contaminants have been discharged through the easement with treated wastewater. This easement is delineated on Figure 1-5.

The portion of the site that is not covered with structures or ponds is generally covered with vegetation (predominantly grasses) and gravel or asphaltic paved surfaces.

The August A. Busch Memorial Wildlife Area is located to the north of the WSS and the Weldon Spring Wildlife Area is located to the south and east of the site. These areas are predominantly covered with trees, brush, and grasses. U.S. Army Reserve property to the west of the site is predominantly covered with trees and grasses.

As indicated above, custody and operations at the site have changed over the years. Some of these changes have resulted in modifications of the buildings and other surface features. In

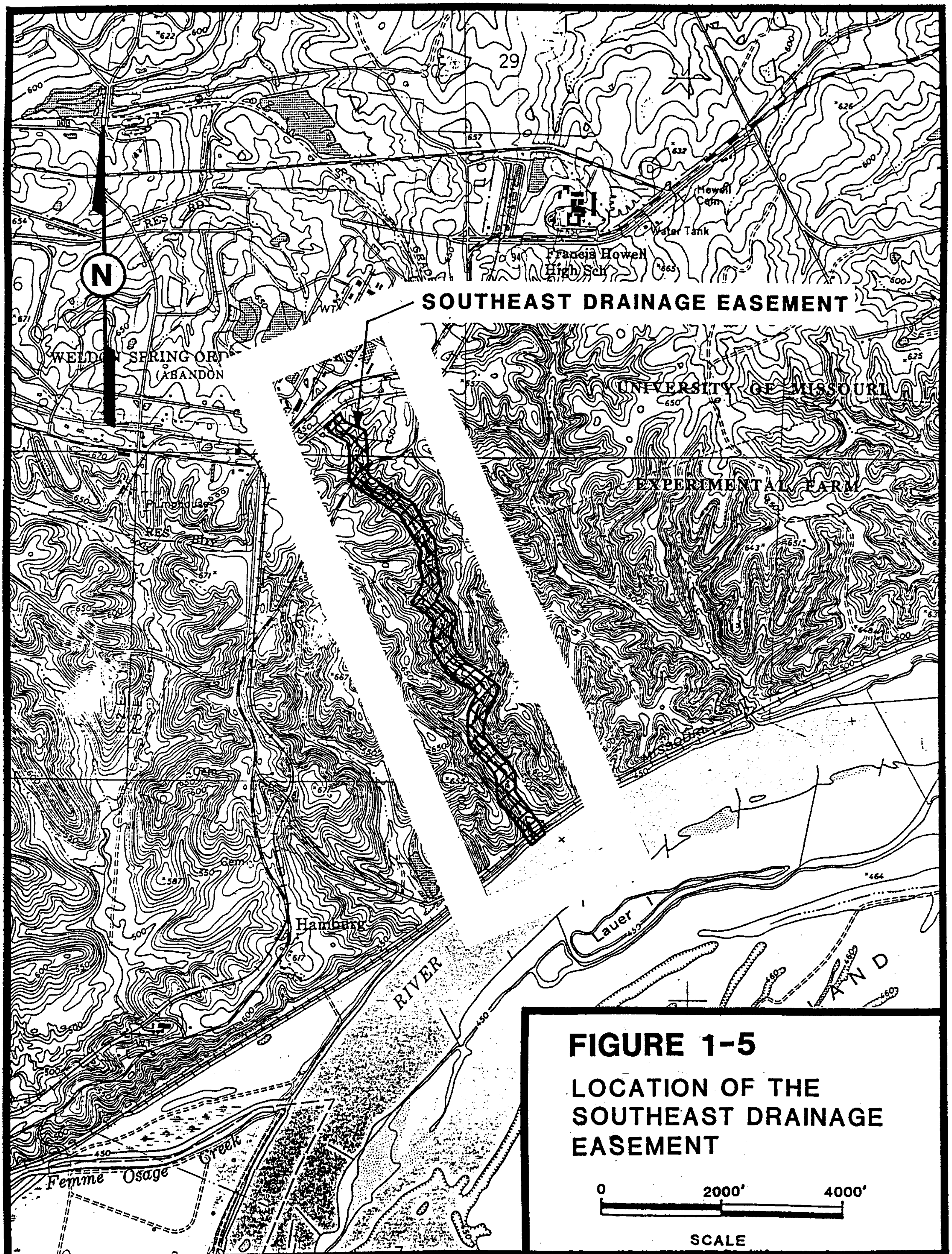


FIGURE 1-5

LOCATION OF THE SOUTHEAST DRAINAGE EASEMENT turn, these modifications have influenced the present state and locations of contamination at and near the site.

1.2.4 Geology

The geology of the WSS has been described in some detail by BNI (1983c, 1984c, 1987) and in lesser detail by Fishel and Williams (1944), Roberts (1951), Krummel (1956), Moylan and Elser (1967), and Kleeschulte and Emmett (1986).

As indicated above, custody and operations at the site have changed over the years. Some of these changes have resulted in modifications of the buildings and other surface features. In turn, these modifications have influenced the present state and locations of contamination at and near the site. Fishel and Williams (1944) performed the first hydrogeologic investigation related to contamination at the site. This investigation was related to the Army's ordnance works operation during World War II. The investigation described the area's general geology, structural geology, groundwater conditions, and occurrences of contamination. Roberts (1951) further describes the geology in the area as it relates to groundwater movement. Krummel (1956) mapped the geology of the area just to the south of the WSS. Moylan and Elser (1967) describe the geology at the raffinate pits area. Kleeschulte and Emmett (1986) provide additional information on the stratigraphic and geologic structure in the vicinity of the raffinate pits. BNI (1983c, 1984c, 1987) provides borehole logs, geologic cross sections, and laboratory data from the chemical plant and raffinate pits areas. The following paragraphs and figures summarize and present an evaluation of the available geological information.

Table 1-1 presents a generalized stratigraphic column, which describes sediments and sedimentary rocks common to Central and East Central Missouri. This column is not to be considered site-specific due to varying thicknessess or absence of formation

TABLE 1-1
GENERALIZED GEOLOGIC STRATIGRAPHIC COLUMN
(After Kleeschulte and Emmett, 1986)

System	Series	Stratigraphic Unit	Depth from ground level to top of formation, in feet	Thickness, in feet	Typical 1/ thickness, in feet	Physical Characteristics	Remarks
Quaternary	Holocene	Alluvium	0	0-65	10-30	Gravelly, silty loam over occasionally gravelly, silty clay loam.	Deposits underlie tributaries to Missouri and Mississippi rivers.
				65-120	100-110	Silty loam, clay, and sand over sand and gravelly sand.	Deposits underlying Missouri and Mississippi river flood plains generally yield large quantities of water to wells. (600-2,600 gal/min).
	Pleistocene	Loess and glacial drift	0	0-150	5-30 30-60	Silty clay, silty loam, clay, or loam over residuum and bedrock, or both.	Yields little water to wells (<5 gal/min)
Pennsylvanian		Undifferentiated	0-120	0-75	--2/	Partly silty red shale with purplish-red to light gray clay.	Limited occurrence. Yields small quantities of water to wells (<1-10 gal/min.)
Mississippian	Meramecian	St. Louis Limestone	0-120	0-105	70-75	Limestone; white to light gray, lithographic to finely crystalline, medium to thick bedded. Contains some shale.	Individually, the rock units yield small to moderate quantities of water to wells (5-50 gal/min). Collectively, these units yield sufficient water to supply most domestic and stock needs.
		Salem Limestone	0-225	0-140	90-130	Limestone; light gray to white, fine to coarsely crystalline, cross-bedded. Some siltstone and shale in lower part.	
		Warsaw Formation	0-345	0-95	70-90	Calcareous shales and interbedded shaly limestone, grades downward to shaly dolomitic limestone.	

Table 1-1 (continued)

System	Series	Stratigraphic Unit	Depth from ground level to top of formation, in feet	Thickness, in feet	Typical 1/ thickness, in feet	Physical Characteristics	Remarks
Mississippian (cont.)	Osagean	Keokuk and Burlington Limestone	0-405	0-220	160-200	Limestone; white to bluish-gray, medium to coarsely crystalline, thick-bedded. Cherty.	(See Mississippian remarks on previous page).
		Fern Glen Limestone	0-500	0-85	50-70	Limestone; yellow-brown, fine grained medium to thick-bedded. Contains appreciable chert.	
	Kinderhookian	Chouteau Limestone	0-580	0-105	50-70	Dolomitic limestone; gray to yellowish-brown, fine-grained, thin to medium-bedded.	
Devonian	Upper	Bushberg Sandstone	0-625	0-20	5-15	Quartz sandstone; reddish-brown, fine to medium grained, friable.	Yields small to moderate quantities of water to wells (5-50 gal/min).
		Lower part of Sulphur Spring Group undifferentiated	0-625	0-60	35-40	Calcareous siltstone, and sandstone with oolitic limestone with some dark, hard, carbonaceous shale.	Group also includes Glen Park and Grassy Creek formations.
Ordovician	Cincinnatian	Maquoketa Shale	0-650	0-75	30-50	Calcareous or dolomitic shale, typically thinly laminated, silty, with shaly limestone lenses.	Yields small quantities of water to wells. (Missouri Geological Survey data indicate Maquoketa shale is absent at the Weldon Spring Site.)
	Champlanian	Kimmswick Limestone	0-710	0-140	90-100	Limestone; white to light gray, coarsely crystalline, medium to thick bedded. Cherty near base.	Yields small to moderate quantities of water to wells (10-50 gal/min).
		Decorah Formation	0-810	0-35	30	Interbedded green and yellow shale with thin beds of limestone.	
		Plattin Limestone	0-840	0-195	100-125	Limestone; light to dark gray, finely crystalline. Thinly bedded; weathered with pitted surface.	

Table 1-1 (continued)

System	Series	Stratigraphic Unit	Depth from ground level to top of formation, in feet	Thickness, in feet	Typical 1/ thickness, in feet	Physical Characteristics	Remarks
Ordovician (cont.)	Champlanian (cont.)	Joachim Dolomite	0-950	0-135	90-110	Dolomite; yellowish-brown, silty thin to thick-bedded. Grades into siltstone, shales common.	(Last remark applies to this unit also.)
		St. Peter Sandstone	0-1070	0-250	120-150	Quartz sandstone; yellowish white to white, fine to medium grained, massive bedded.	Yields moderate quantities of water to wells (10-40 gal/min). Everton formation discontinuous.
		Everton Formation	0-850	0-65	0	Sandy dolomite.	
	Canadian	Powell Dolomite	0-950	0-65	50-60	Dolomite; medium to finely crystalline, often sandy, occasionally cherty or shaly.	Generally yields small quantities of water to wells (<10 gal/min).
		Cotter Dolomite	0-1250	75-275	200-250	Dolomite; light gray to light brown, medium to finely crystalline, cherty. Argillaceous, interbedded with green shale.	
		Jefferson City Dolomite	100-1500	145-225	160-180	Dolomite; light brown to brown, medium to finely crystalline.	
		Roubidoux Formation	350-1700	150-170	150-170	Dolomitic sandstone.	Yields moderate to large quantities of water to wells (10-300 gal/min).
		Gasconade Dolomite	500-1850	250	250	Cherty dolomite; Gunter Member is arenaceous dolomite.	Gunter Member is about 30 feet thick.
Cambrian	Upper	Eminence Dolomite	750-2100	190	200	Dolomite; medium to massively bedded, light gray, medium to coarse-grained.	Yields moderate to large quantities of water to wells (10-500 gal/min).
		Potosi Dolomite	950-2250	100	100	Dolomite; massive, thickly bedded, medium to fine grained. Abundant quartz druse.	Freshwater only in southwest part of St. Charles County and saline water elsewhere in county.

TABLE 1-1 (continued)

System	Series	Stratigraphic Unit	Depth from ground level to top of formation, in feet	Thickness, in feet	Typical 1/ thickness, in feet	Physical Characteristics	Remarks
Cambrian (cont.)	Upper (cont.)	Derby and Doe Run Dolomites	1050-2350	140	150	Dolomite; thin to medium bedded alternating with thin bedded silt-stone and shale.	Hydrologic characteristics unknown in St. Charles County. Is a confining bed elsewhere in state.
		Davis Formation	1200-2500	170	170	Contains shale, siltstone, fine-grained sandstone, dolomite, and limestone conglomerate.	
		Bonneterre Dolomite	1350-2650	430	400	Dolomite; typically a light gray, medium to fine grained, medium bedded.	Yields unknown in St. Charles County; however, water probably is saline.
		Lamotte Sandstone	1800-3100	460	450	Predominantly quartzose sandstone.	
Precambrian			2200-3500			Igneous rocks.	Yields no water.

1 "Typical thickness" refers to thickness of formation normally encountered while drilling.

2 -- indicates insufficient data for estimate.

at the WSS (Kleeschulte and Emmett, 1986). Data on water-yielding capabilities of the different formations or formation groups are included.

1.2.4.1 Overburden

Overburden, or unconsolidated materials, present at the site can be categorized into six units (BNI, 1984c and 1987):

- o Fill/Topsoil
- o Wind deposits (loess)
- o Ferrelview Formation
- o Clay till
- o Basal till
- o Residuum

The relative positions of the different units are listed above with fill/topsoil being the youngest sediments. BNI depicts the total thickness for the unconsolidated materials as well as that of some of the individual units on isopach maps (1987). The maps are reproduced here in Figures 1-6 through 1-9. The thicknesses depicted are based on boring logs from studies performed in 1983 and 1986 (BNI, 1984c, 1987). Additional boring information from further site characterization will allow for a more accurate delineation of the overburden materials and a modification of the contours. An examination of Figure 1-6 indicates that unconsolidated material underlies the entire site with thicknesses ranging from less than 20 feet to more than 55 feet. The overburden is thicker along the ridge top trending north-south through the middle of the chemical plant area. The thinner portions generally lie along the eastern and western flanks of the site.

Topsoil at the site varies in thickness from 0.5 to 3.5 feet, and is a black, organically rich, silty clay or clayey silt (BNI,

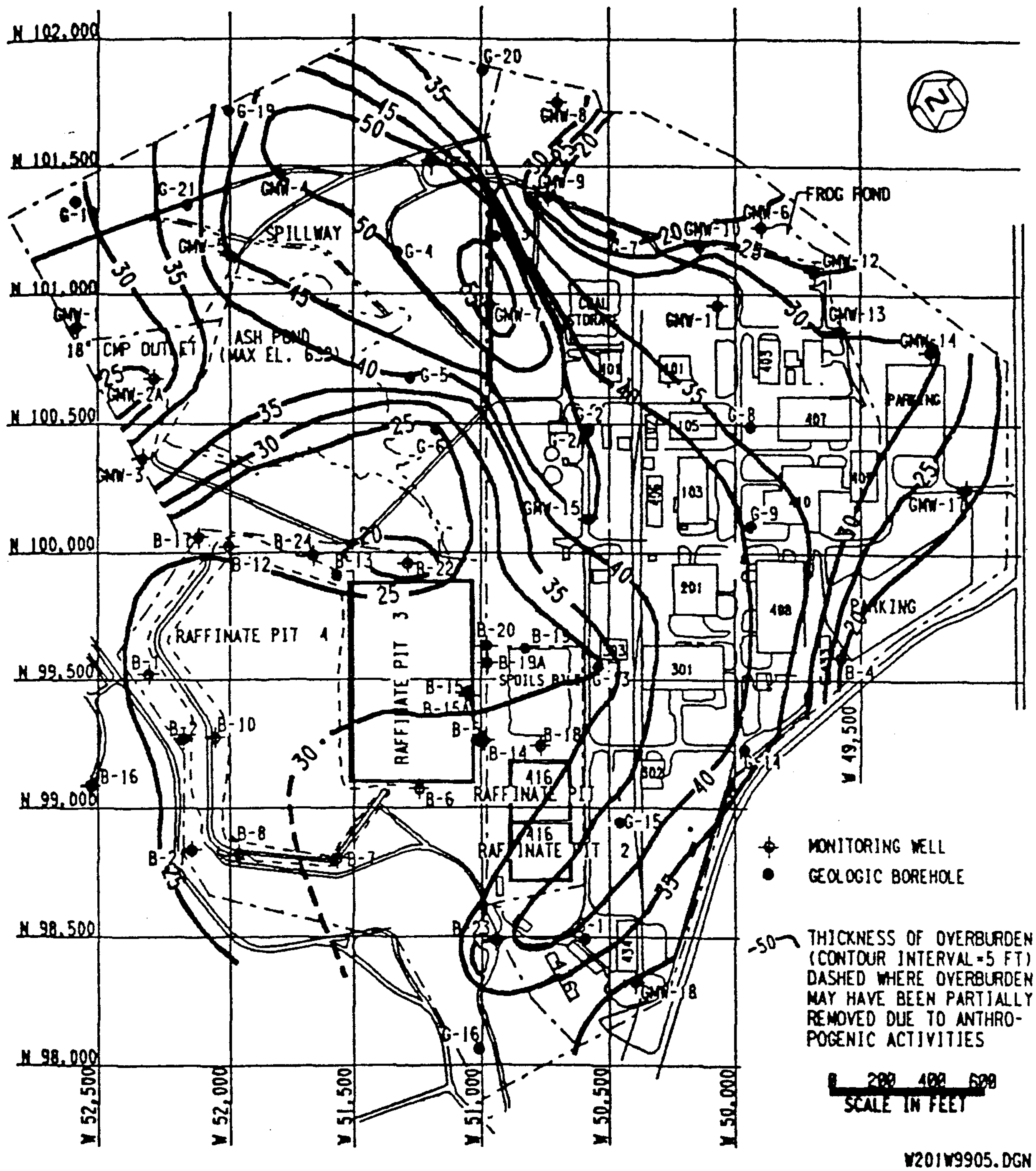


FIGURE 1-6

ISOPACH OF OVERBURDEN

SOURCE : BNI, 1987

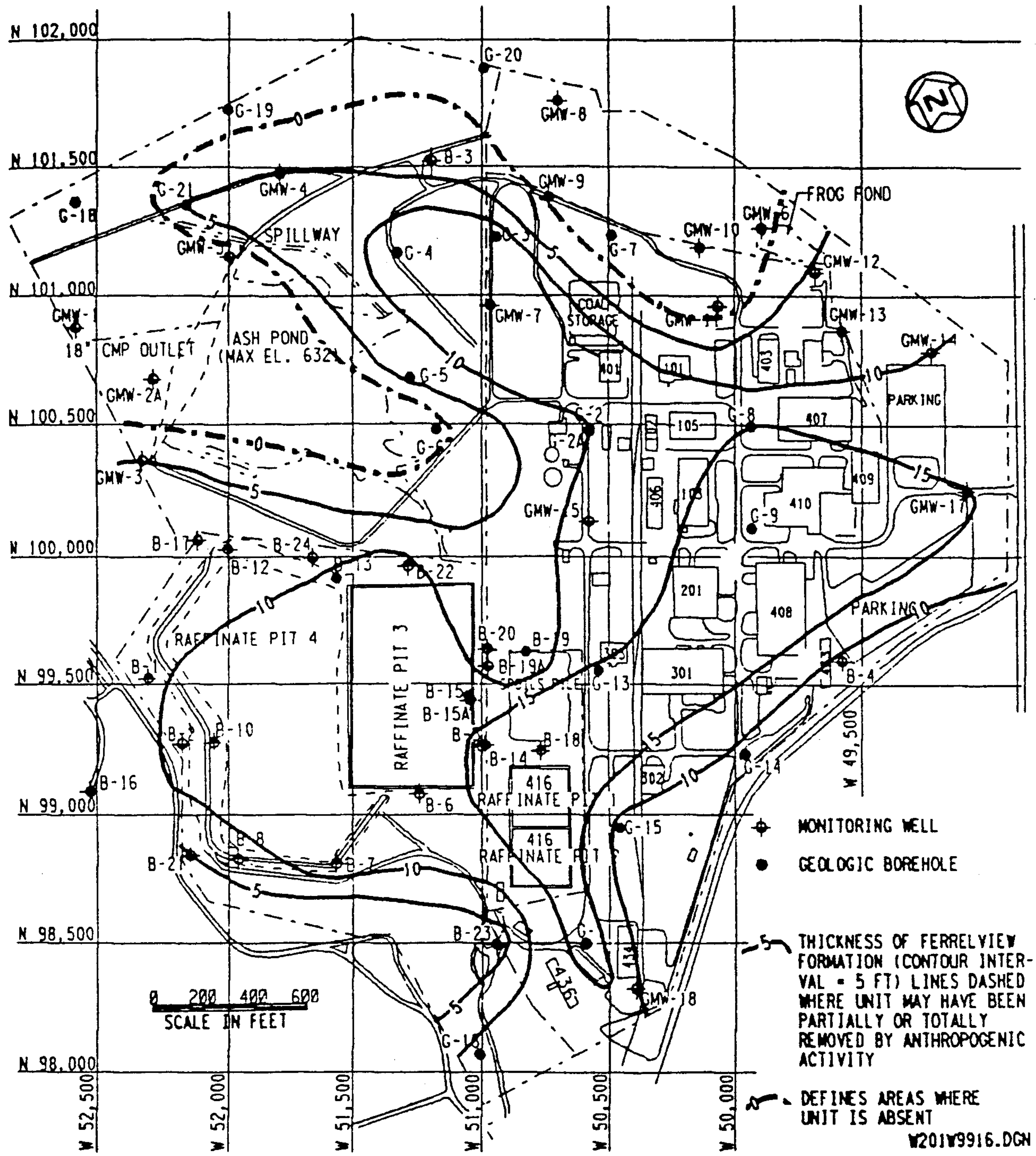


FIGURE 1-7

FERRELVIEW ISOPACH

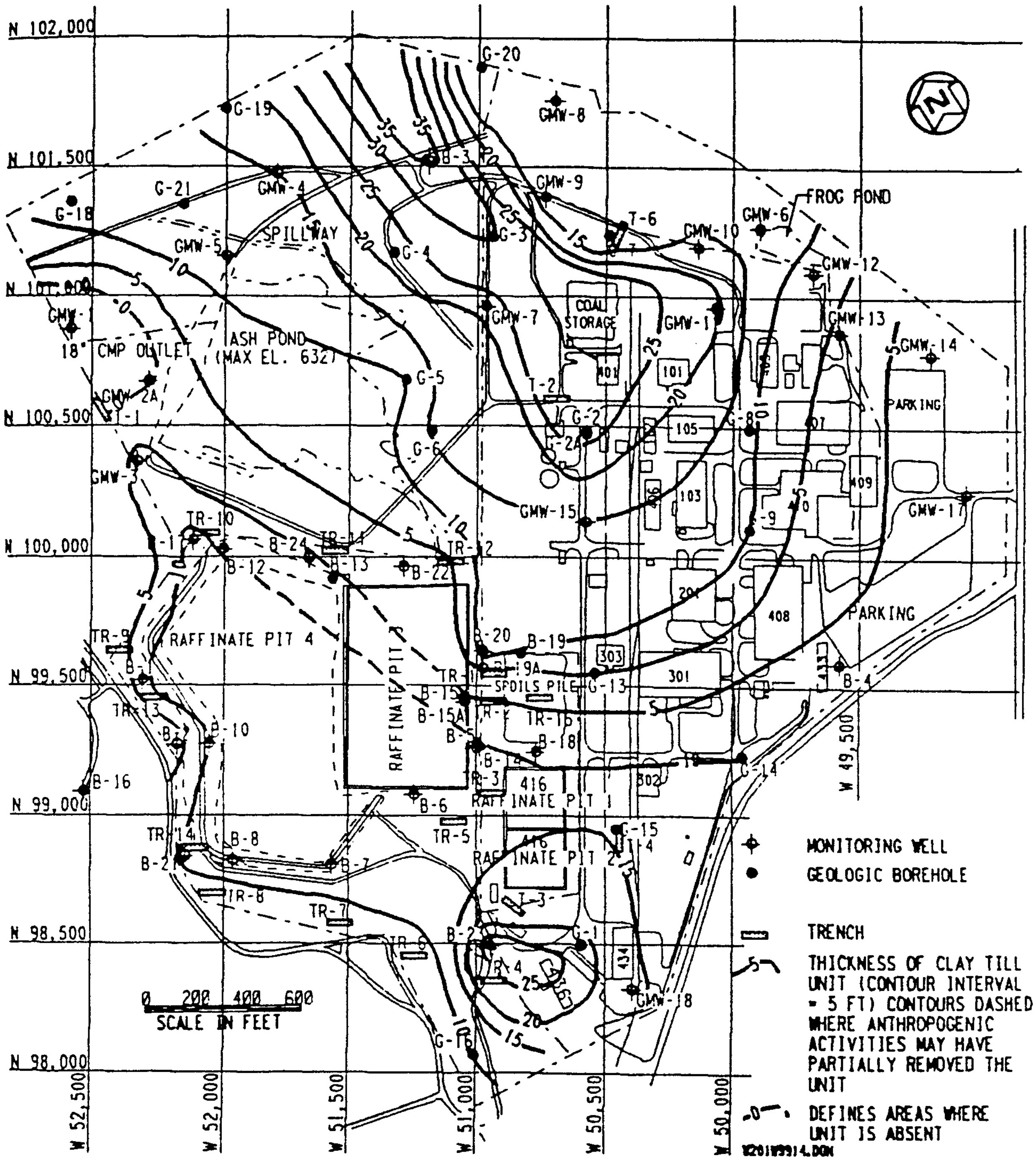


FIGURE 1-8

CLAY TILL ISOPACH

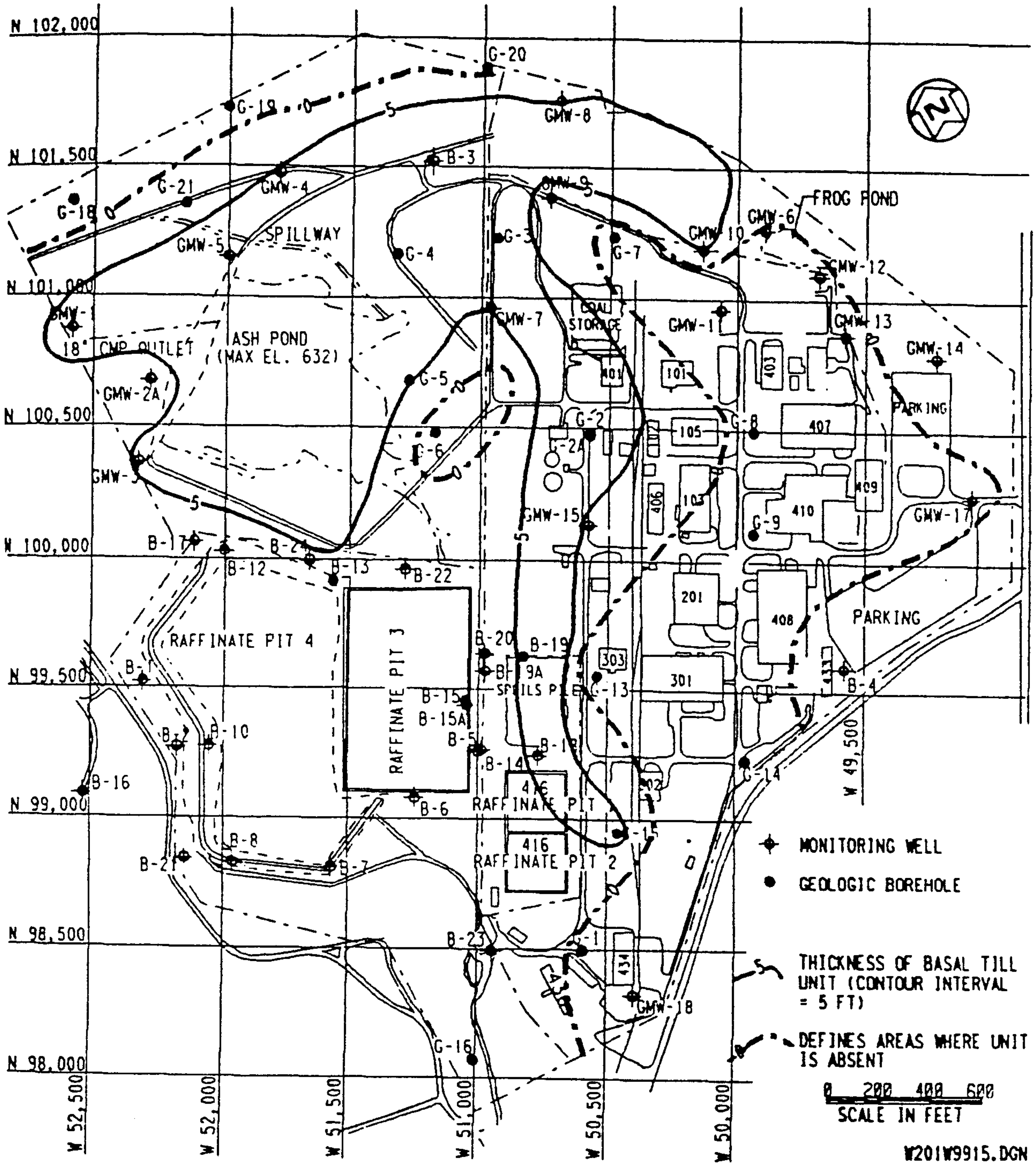


FIGURE 1-9

BASAL TILL ISOPACH

1984c and 1987).

The fill portion is quite variable in composition and thickness and is believed to be primarily local site soils which have been transported and recompacted. The thickest areas of fill are probably at the raffinate pits where up to 26 feet of fill are reported (BNI, 1987).

Loess deposits with thicknesses from 0 to 10.5 feet overlie the Ferrelview Formation or clay till across the site. The distribution and thickness of the loess in the area is quite variable and not well defined (BNI, 1987). Extensive re-working of these unconsolidated sediments occurred during original site construction.

Figure 1-7 illustrates thicknesses of the Ferrelview Formation at the WSS. The Ferrelview Formation is a dark yellowish-orange to brown silty clay to clayey silt with gray mottling. Iron oxide nodules and pyrolusite (manganese oxide) veins and stringers are common in the unit (BNI, 1987). The formation covers most of the site with thicknesses to more than 15 feet. The Ferrelview Formation is apparently absent under Ash Pond and along the northern edge of the site.

The clay till underlying the Ferrelview Formation is a yellowish-brown silty clay to clayey silt. The unit contains sand and gravel-sized particles and pyrolusite veins and stringers (BNI, 1987). Thicknesses of the unit are depicted in Figure 1-8. The unit apparently covers all of the site, except just north of Ash Pond. Thicknesses exceed 35 feet near the northernmost corner of the site.

The basal till unit underlies the clay till unit. Thicknesses of this unit are shown in Figure 1-9. The unit exceeds 5 feet in thickness under Ash Pond and the western portion of the WSCP and is absent beneath the main portion of the WSCP. The basal till is a yellowish-brown sandy, clayey silt with angular chert gravel and cobbles (BNI, 1987).

The residuum, located at the base of the unconsolidated materials, is typically a red to yellow gravelly clay to gravelly silt. The thickness of the residuum ranges from 0 to approximately 23 feet at the WSS. The distribution and thickness of the residuum in the area is apparently related to localized weathering and erosion (BNI, 1987).

BNI gives summaries of soil testing data for samples from the different overburden units (1987). These data are summarized in Table 1-2. BNI provided the following discussion of the data:

> "Comparison of grain size distributions of the four units indicates that the basal till has the highest gravel content, the clay till has the highest sand and clay content, and the loess has the highest silt content. The Ferrelview Formation contains a higher percentage of silt than the clay till, yet the Ferrelview is thought to be derived from the clay till. The higher silt content of the Ferrelview may reflect loess deposited contemporaneously with the Ferrelview.
>
> "The parameters measured in the soil test program most directly related to the attenuation of radionuclides were effective cation exchange capacity (CEC) and distribution ratio. The clay till unit exhibited the highest cation exchange, followed by the Ferrelview Formation and finally the basal till. The loess unit was not examined in this study due to its limited areal extent on the site. The results of these tests are as could be expected from the percentages of clay in each unit. The clay till has the highest clay content and thus has the highest surface area and largest number of surface charged particles available for cation exchange reactions. The basal till has the least amount of clay and contains significant amounts of quartz and amorphous silica (chert) which provide less possibility for cation exchange sites.
>
> "Distribution ratios were measured using a 10.44 mg/l uranium source solution. The results of the distribution ratio tests indicate no correlation between absorption capacity for radionuclides and cation exchange capacity, with the basal till having the highest distribution ratio and the clay till having the lowest distribution ratio.

TABLE 1-2 OVERBURDEN TESTING SUMMARY (from BNI, 1987)

Unit	Statistic 1/	% of Grain Size: Gravel	Sand	Silt	Clay	Liquid Limit 2/	Plasticity Index	Unified Soil Class.	Specific Gravity (g/cm^3)	Unit Weight (lb/ft^3): Dry	Wet	Moisture Content (%)	Centrifuge Moisture Equiv.
Loess	xa	0	4.4	64	31.6	30	13	CL	2.58	98.8	110.0	--	--
	s	0	1.3	3	4.0	--	--	--	--	7.1	12.4	--	--
	n	5	5	5	5	1	1	1	1	6	6	0	0
Ferrelview Formation	xa	2.8	9.8	49.6	39.6	52.2	35.1	CL-CH	2.61	101.3	122.3	24.7	45.4
	s	4.1	5.5	6.9	10.9	7.8	7.5	--	0.07	12.4	9.4	0.6	8.5
	n	10	10	10	10	8	8	8	11	8	8	7	5
Clay Till	xa	0.4	22.4	31.7	45.6	50.3	34.2	CL	2.60	104.8	123.8	19.3	39.7
	s	1.0	4.5	2.4	4.5	10.5	8.4	--	0.09	4.4	7.0	3.0	5.7
	n	18	18	18	18	16	16	16	18	14	14	15	13
Basal Till	xa	10.7	18.7	39.8	30.8	41.6	23.6	GC-CL	2.45	99.8	118.6	20.9	38.5
	s	17.1	14.3	23.0	8.1	14.1	11.7	—	--	7.8	8.1	3.8	2.1
	n	6	6	6	6	5	5	5	1	5	5	3	2
Fill	xa	20	48	19	13			SM	2.45				
	s	--	--	--	--			--	--				
	n	1	1	1	1			1	1				

1/ Statistics given are: xa - mean; s-sample standard deviation; n - number of test results in computation of statistic

2/ Blanks indicate data of the type indicated were not available in the Bechtel National (1987) reference.

3/ Void ratio = (specific gravity X unit weight of water -1)/dry unit weight

4/ Specific retention = centrifuge moisture equivalent X 0.80

5/ Specific yield = porosity - specific retention

6/ Saturation = (specific gravity X moisture content)/void ratio

7/ Activity = plasticity index/percent of clay

TABLE 1-2 OVERBURDEN TESTING SUMMARY (from BNI, 1987)(cont.)

Unit	Statistic 1/	Void Ratio 3/	Porosity (%)	Specific Retention (%) 4/	Specific Yield (%) 5/	Saturation 6/	Activity 7/	Effective Cation Exch. Cap. (meq/100G)	Distribution Ratio (ml/g)
Loess	xa	--	--	--	--	--	--	--	--
	s	--	--	--	--	--	--	--	--
	n	--	--	--	--	--	--	0	0
Ferrelview Formation	xa	0.61	38	36	2	100	0.89	60.3	54.8
	s	--	--	--	--	--	--	0.1	9.7
	n	--	--	--	--	--	--	2	2
Clay Till	xa	0.55	35	32	3	91.2	0.75	69.0	34.2
	s	--	--	--	--	--	--	11.7	6.2
	n	--	--	--	--	--	--	2	2
Basal Till	xa	0.53	35	31	4	96.6	0.77	29.0	206
	s	--	--	--	--	--	--	--	--
	n	--	--	--	--	--	--	1	1
Fill	xa	--	--	--	--	--	--		
	s	--	--	--	--	--	--		
	n	--	--	--	--	--	--		

1/ Statistics given are: xa - mean; s-sample standard deviation; n - number of test results in computation of statistic

2/ Blanks indicate data of the type indicated were not available in the Bechtel National (1987) reference.

3/ Void ratio = (specific gravity X unit weight of water -1)/dry unit weight

4/ Specific retention = centrifuge moisture equivalent X 0.80

5/ Specific yield = porosity - specific retention

6/ Saturation = (specific gravity X moisture content)/void ratio

7/ Activity = plasticity index/percent of clay

> Visual examination of the samples by laboratory personnel indicates that the basal till sample has the highest organic content of the samples tested. This suggests that the reactions observed in the basal till sample may be related to organic matter content rather than cation exchange capacity, since CEC measurements show the basal till has the lowest CEC. The implication of this reasoning is that the ability of the basal till to immobilize radionuclides is directly related to organic content and the geochemical environment and may vary both spatially and temporally."

Quartz, limonite, and calcium carbonate (limestone) were noted in particle size analyses of the overburden (BNI, 1987). These rock minerals are of interest as they influence solubility, groundwater chemistry, and possibly the physical nature of the unsaturated zone and the aquifer. In addition, the mineralogical composition is useful in assessing the leaching and/or attenuation of contaminants. The available data are not quantitative.

1.2.4.2 Bedrock

Geologic cross sections have been drawn to show the overburden materials and the upper part of the bedrock at the WSS with hydraulic conductivity (permeability) information. The locations of these cross sections are presented in Figure 1-10 and the cross sections are shown in Figures 1-11 through 1-13. Estimated thicknesses of the bedrock units are shown in Table 1-3. Cross-sections will be modified as additional data are obtained under this and other (e.g. soil, geotechnical, geophysical) investigative programs.

The near-surface rock units at the site are sedimentary. The first bedrock unit underlying the overburden is the Keokuk and Burlington Limestones or the Burlington/Keokuk Formation. This is a white to bluish-gray, medium to coarsely crystalline, thick bedded limestone containing chert. At the site, the Burlington/Keokuk Formation can be subdivided into two units. The uppermost unit is moderately to highly weathered and fractured,

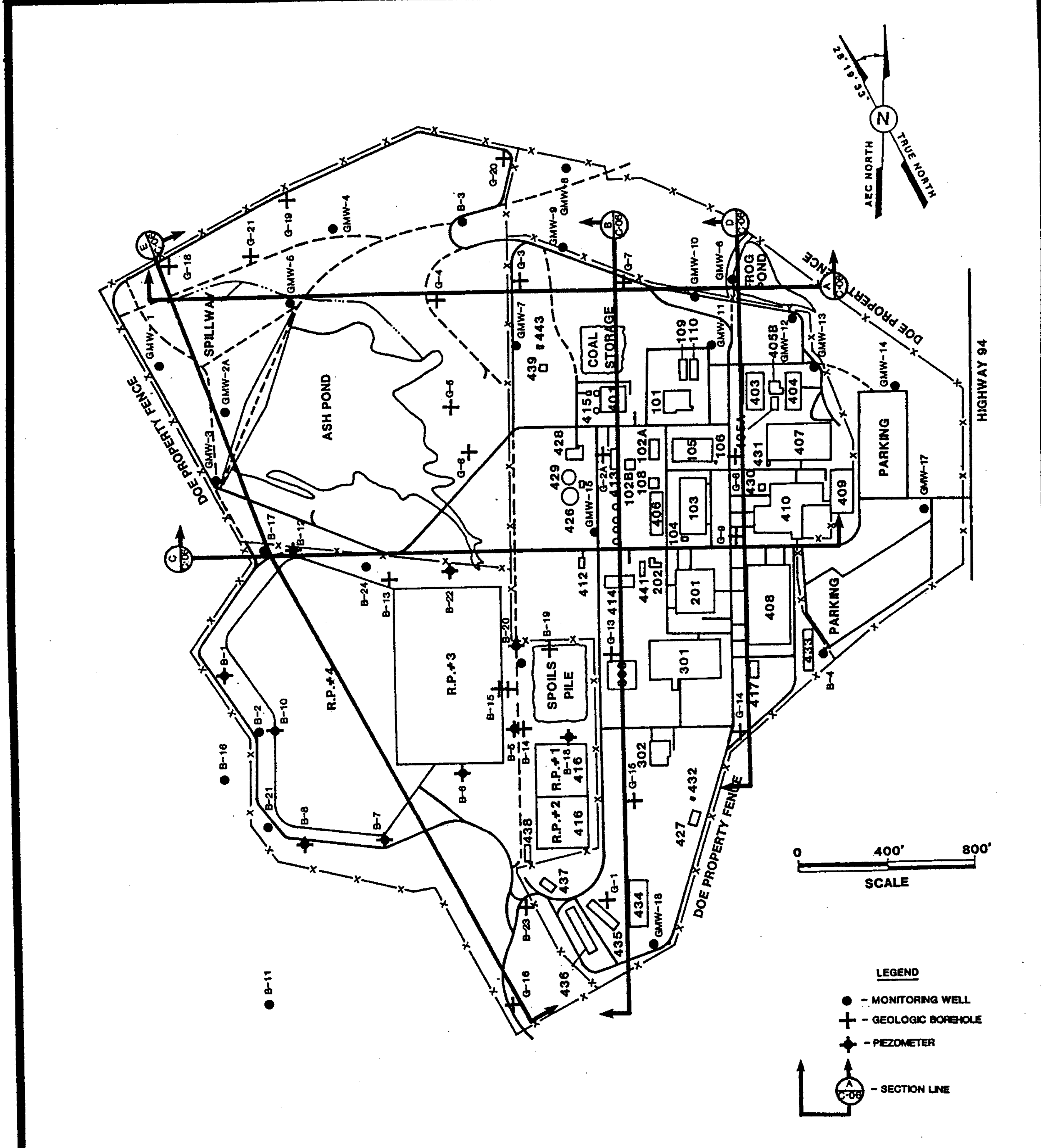


FIGURE 1-10

LOCATION OF CROSS SECTIONS

SOURCE : BNI, 1987

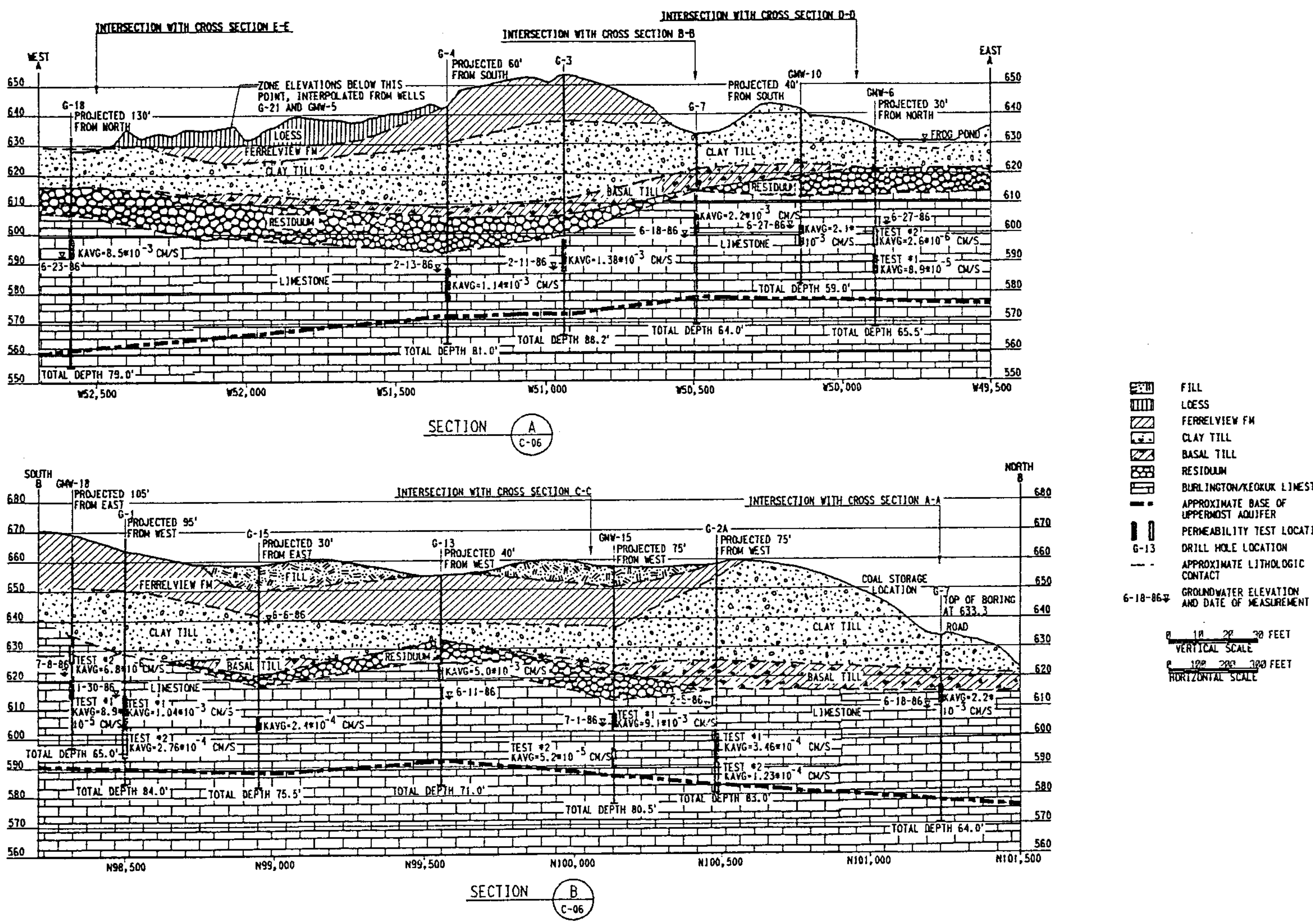


FIGURE 1-11

GEOLOGIC CROSS SECTIONS A-A AND B-B

SOURCE : BNI, 1987

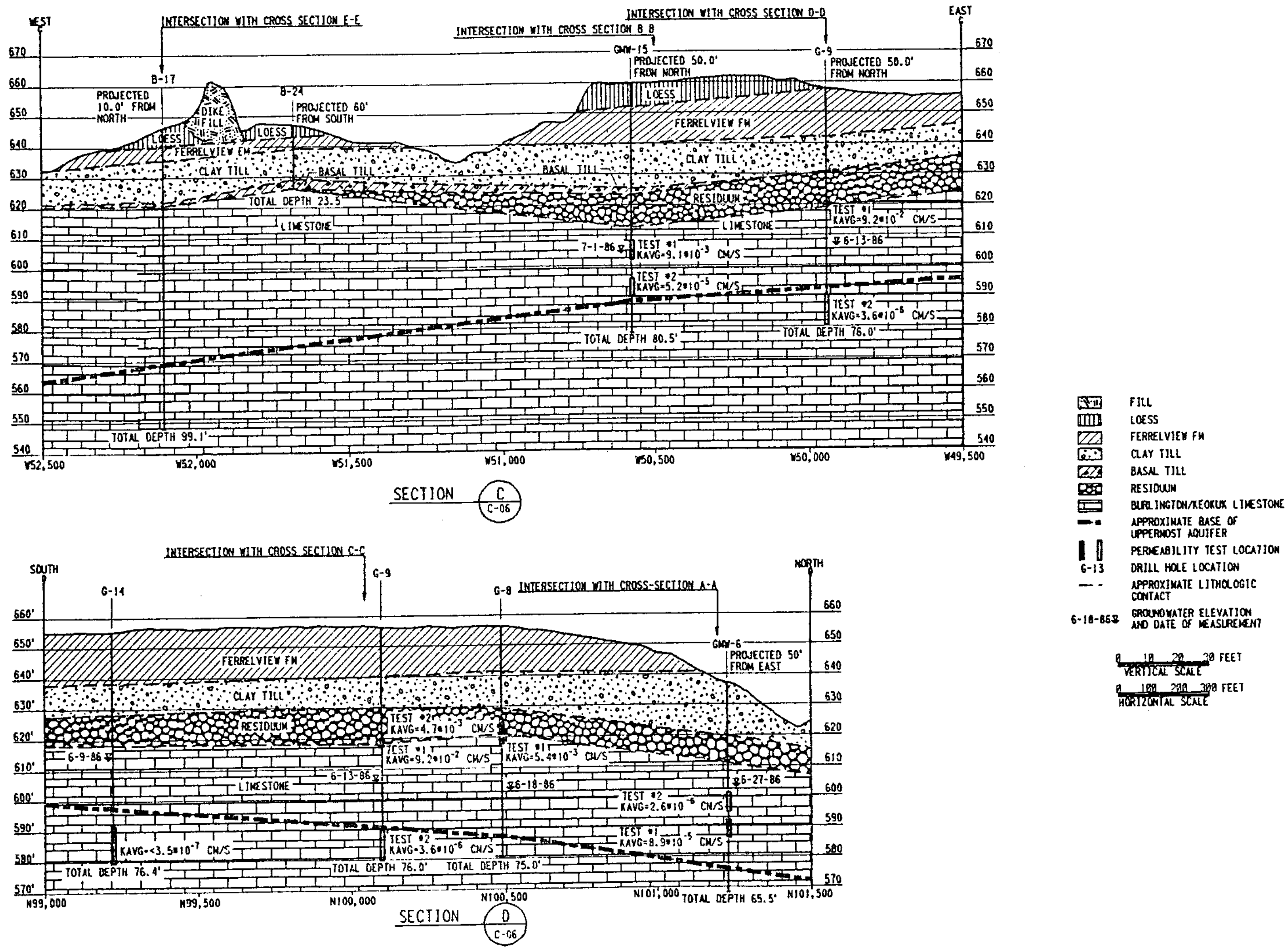


FIGURE 1-12

GEOLOGIC CROSS SECTIONS C-C AND D-D

SOURCE : BNI, 1987

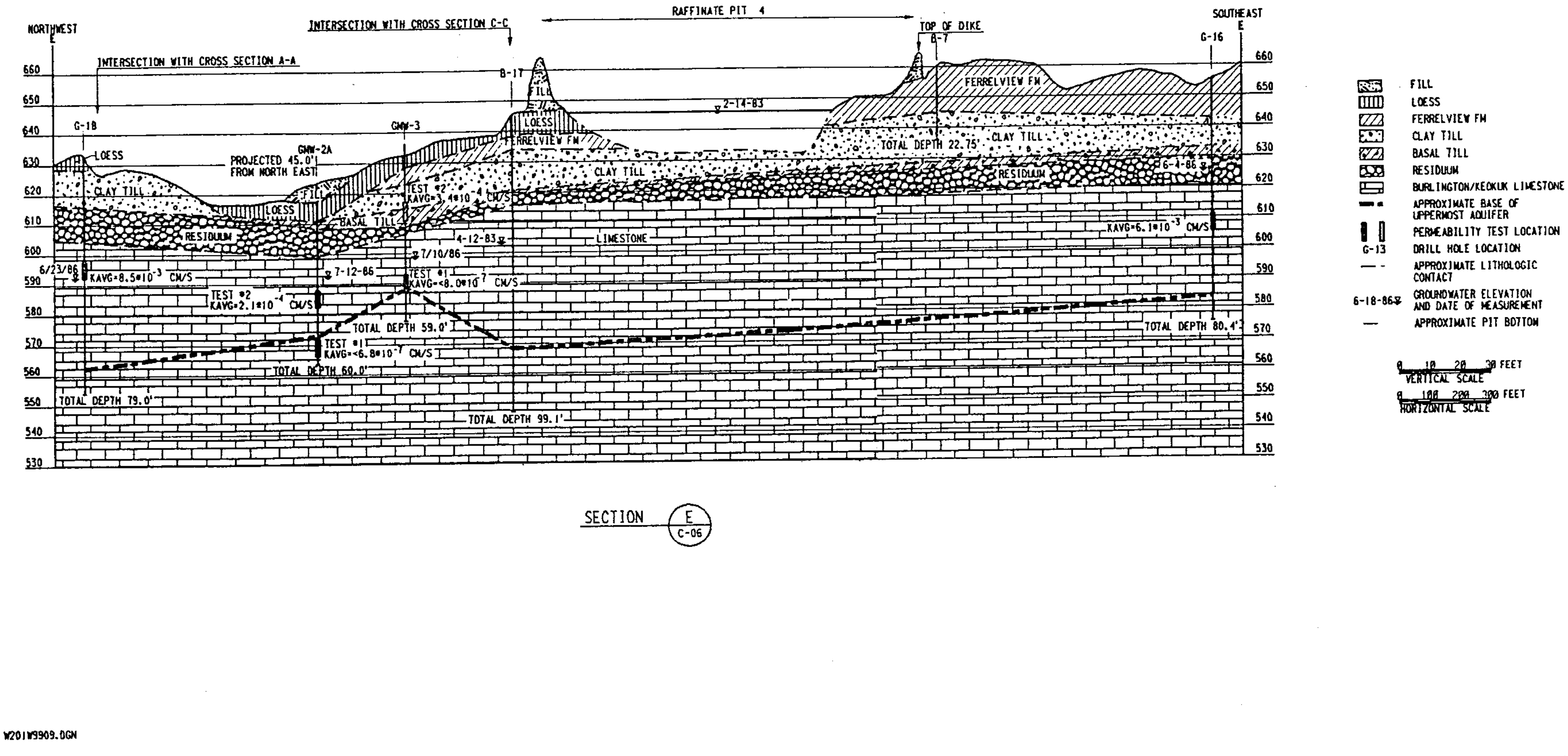


FIGURE 1-13

GEOLOGIC CROSS SECTION E-E

SOURCE : BNI, 1987

TABLE 1-3

ESTIMATED THICKNESSES OF BEDROCK UNITS AT WSS

Stratigraphic Unit	Estimated Thickness, ft
Burlington/Keokuk Formation	160
Fern Glen Limestone	50
Chouteau Limestone	20
Bushberg Sandstone	7
Kimmswick Limestone	90
Decorah Formation	30
Plattin Limestone	120
Joachim Dolomite	90
St. Peter Sandstone	135

yellowish brown to white and consists of approximately 50% chert. This unit contains solution features ranging from vugs (up to 2 in. diam.) to small cavities (up to 5 ft diam.).

These cavities are generally filled with sand/chert gravel mixtures. Solution features and predominant fractures appear to be oriented to the bedding. Figures 1-11 through 1-13 depict the estimated base of the uppermost unit as defined by lithologic logs and hydraulic conductivity testing (BNI, 1987). Thicknesses of this unit vary from approximately 20 ft to greater than 50 ft. The variability in thickness is attributed to a variance in the depth of weathering of the limestone. There is no defined base of the weathered zone.

The lower unit of the Burlington/Keokuk Formation is slightly weathered to fresh, slightly fractured, to brownish-gray to gray limestone, and contains approximately 30% chert.

From a study of the core samples the unit appears to be massive. Solution features are limited to occasional vugs in the upper portion. Pressure solution features and/or shale interbeds are common (BNI, 1987). The thickness of the unit is not defined, but is estimated to be approximately 130 ft, based on regional data presented in Table 1-1. A 30-ft thickness for the upper unit is assumed.

The formation underlying the Burlington/Keokuk at the WSS is the Fern Glen Limestone. This is a thin to thick bedded, crystalline to argillaceous limestone. Chert is common in this formation with the occurrence of occasional calcareous shale interbeds. The thickness of this unit at the site is estimated as approximately 50 ft.

Brief descriptions of the units from the base of the Fern Glen Limestone through the St. Peter Sandstone are as follows (after BNI, 1987):

Chouteau Formation	Conformably underlies Mississippian age, Osagean series which includes the Fern Glen Limestone and the Burlington/Keokuk Limestone. Thin-bedded limestone containing a few shale partings and localized argillaceous material and chert. Unconformably overlies the Bushberg Sandstone.
Bushberg Sandstone	Fine to medium-grained quartzose sandstone with variable carbonate content. Unconformably overlies the Kimmswick Limestone.
Kimmswick Limestone	Composed of thick-bedded, high-purity limestone with local concentration of chert.
Decorah Formation	Thin-bedded argillaceous limestone with intercalated calcareous shales. Thin bed of metabentonite separates the Plattin and Decorah formations.
Plattin Limestone	Thin to thick-bedded, microcrystalline to fine-grained limestone.
Joachim Dolomite	Thin to thick-bedded dolomite which grades into siltstone.
St. Peter Sandstone	Composed of fine to medium-grained, massive-bedded, quartzose sandstone.

Krummel (1956) provides more detailed descriptions of most of the bedrock units including their lithologies.

The Burlington/Keokuk Formation, as indicated above, contains solution features. Also the Kimmswick Limestone contains stylolites (pressure solution features), commonly along bedding planes, and is well jointed and may contain caverns (Krummel, 1956). The possible existence of migration pathways in the other bedrock is not defined. However, water for wells is obtained from the permeable zones of many of the formations (see Table 1-1). Dye tracing studies by Dean (1983a, 1983b, 1983c, 1984a, 1984b, 1985) indicate the presence of subsurface pathways.

Thicknesses of the deeper units at the site are unknown but can be estimated from the regional data shown in Table 1-1.

Figure 1-14 (in pocket) represents the configuration of the upper surface of the Burlington/Keokuk Formation at the site, and is based on recent (1988) investigations. BNI and MKF have generated contour maps of the bedrock surface (BNI, 1987; MKF, 1987b). Those maps present a similar configuration of the bedrock surface.

The rocks in the area have a regional strike of N60o$_{W}$ and regional dip of approximately 1/2 degree to the northeast. The regional dip is predominantly from the Ozark Dome, though several other features may influence the dip. The Division of Geology and Land Survey of the MDNR has recently mapped a fault, trending east-west, about one mile north of the WSS. The fault has approximately 60 feet of vertical displacement (memo to Dave Bedan from Dave Hoffman, MDNR, June 10, 1988). Roberts (1951) has identified two major joint sets in the area; the first set trends between N30°E to N72°E and the other set trends between N30°W to N65°W. These joints are present in the Burlington/Keokuk, the Chouteau, and the Kimmswick (Roberts, 1951). Krummel (1956) and Kleeschulte and Emmett (1986) indicated they are vertical or nearly vertical.

1.2.5 Surface Water Hydrology

The site is located on the drainage divide between the Mississippi and Missouri rivers. The northern part of the WSS drains to Schote Creek, then to Dardenne Creek, and then to the Mississippi River. Drainage from the southern portion of the site flows to unnamed tributaries flowing into the Missouri River. Topographic maps are available for the site and vicinity. These include a range of map scales from 1:24000 (USGS, 1982) to 1:600 (Surdex Corp., 1983) and were produced in the period from 1982 to 1987.

Surface water drainages from the WSS are shown in Figure 1-15. Surface water in the Mississippi River drainage is divided into three major drainage basins: Ash Pond area, Frog Pond area and raffinate pit vicinity. Both the Ash Pond and raffinate pit vicinity drainages enter an unnamed tributary to Schote Creek and flow on to Lake 35. Both streams lose water to the subsurface. Some of this lost flow resurfaces at Burgermeister Spring (Dean, 1985). Surface water from Frog Pond exits the WSCP and flows into Lake 36. Overflow from Lake 36 enters Schote Creek and flows into Lake 35.

Lake 35 has lost water to the subsurface since its construction (Meyer, 1987). Lake 35 overflows to Schote Creek only during extreme precipitation events. Schote Creek joins Dardenne Creek just east of Highway K.

In early 1987, a small swallow hole opened near the headwaters of Lake 35. Missouri Department of Natural Resources (MDNR) dye studies determined that some of the lost water resurfaces in Lake 34 and at a spring northwest of Lake 34 near Twin Island Lake. MDNR dye studies are discussed in Section 1.2.7.2. Subterranean flow surfacing at Burgermeister Spring flows into Lake 34. Lake 34 outflow enters an unnamed tributary of Dardenne Creek. Dardenne Creek flows northeast to the Mississippi River.

The 20 acres of the WSS that are in the Missouri River drainage are located in the southeast portion of the WSCP. Drainage is overland via the Southeast Drainage Easement, an intermittent stream valley approximately 1.5 miles long.

Estimates of recharge or discharge via these associated systems are not available. Kleeschulte et al, (1986) present results of streamflow measurements at 102 sites taken in April 1985 from Dardenne Creek tributaries for seepage run determinations. Other streamflow measurements for the vicinity of the WSS are also included. Further discussion of this surface-subsurface

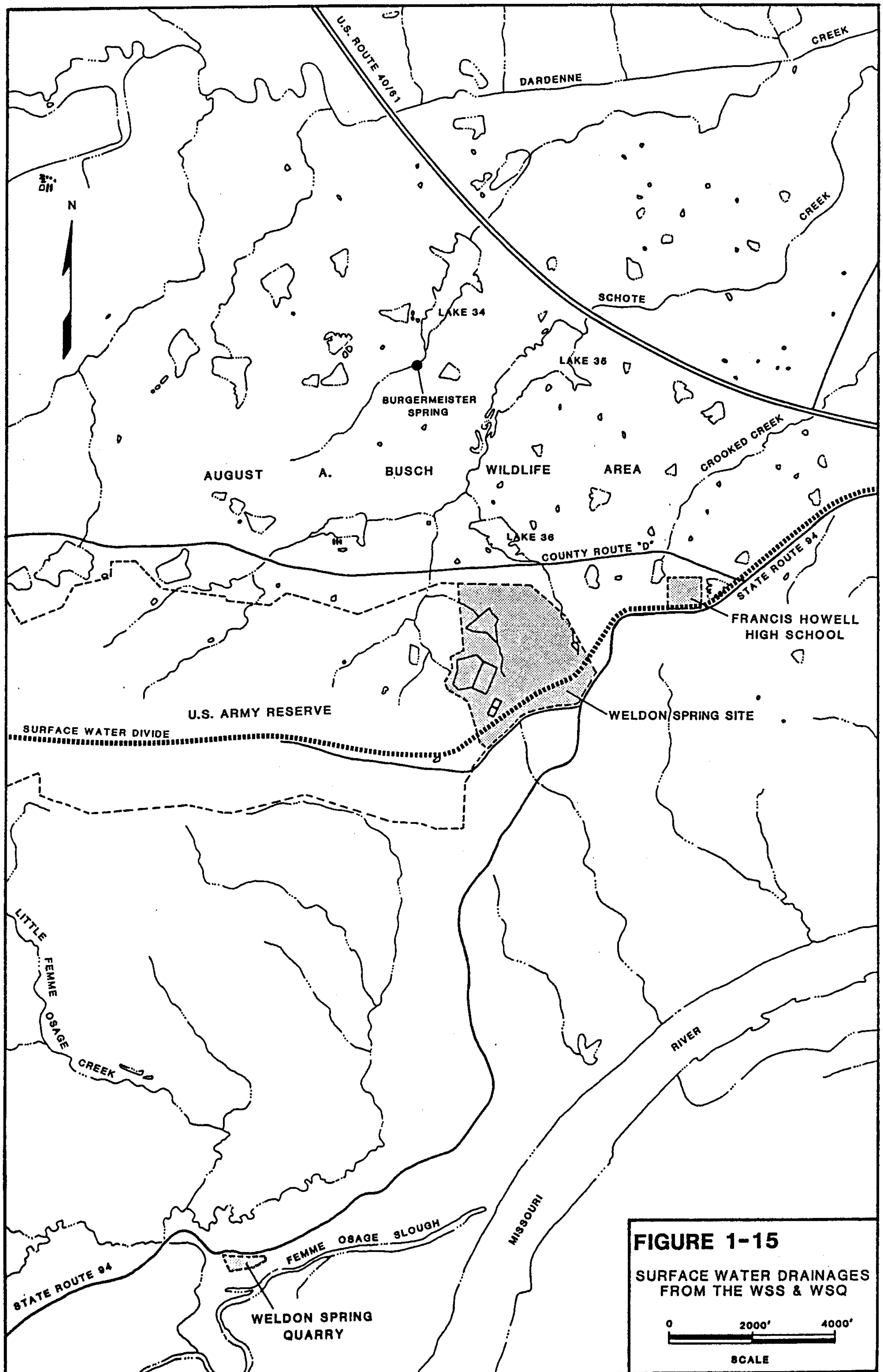


FIGURE 1-15

SURFACE WATER DRAINAGES FROM THE WSS & WSQ interrelationship is included in Section 1.2.7.

Runoff from the southern portion of the site and much of the chemical plant area flows southward to the Missouri River. Some of the rainwater and snow melt enter various man-made drains in the chemical plant area. These drains flow into the process sewer which exits southward from the site to a drainage ditch and flows to the Missouri River.

As discussed earlier, four raffinate pits exist at the site -- Raffinate Pits 1, 2, 3, and 4. These are described in Table 1-4. They have served as sources of contamination (Section 1.2.8) and also provide some driving head for moving contaminants into the subsurface system. Recharge estimates for water in the raffinate pits are available for months April through October over a 3-year period (1983-1985) (BNI, 1986a). Water balance studies indicated total water losses to be on the order of one and one-half to two millimeters drop in elevation per day. Cumulative changes over a 7-month period were substantial enough to document loss of water, though magnitude of loss on a per-day basis was close to the accuracy of the monitors used. The BNI report notes that a 2 mm loss would translate to a permeability rate of 10^{-7} cm/sec. When evapotranspiration is accounted for, an average loss from the pits of less than 1 mm depth per day or less than one gpm/acre of pit area is estimated.

The U.S. Army Corps of Engineers has developed some preliminary estimates of hydrologic parameters for Schote Creek at the site (DOE, 1987). The 100-year and 500-year flood peak discharges for the main stem of Schote Creek are 2,100 and 2,700 cfs, respectively. The 500-year flood elevation near the raffinate pits was determined to be about 530 feet, which is considerably lower than the elevation of the site (DOE, 1987).

TABLE 1-4

APPROXIMATE RAFFINATE PIT SIZES (MKF, 1987b)

Pit No.	Design Capacity (c.y.)	Sludge Vol. (c.y.)	Ponded Water (gal.)	Surface Area (ac.)	Surface Water Elevations (ft. MSL)	Avg. Water Depth (ft.)
1	18,500	17,400	1,600,000	1.2	661.3	4
2	18,500	17,400	1,600,000	1.2	661.5	4
3	166,700	129,600	9,700,000	8.1	659.5	3.7
4	444,400	55,600	43,200,000	15.0	646.4	8.8

1.2.6 Vadose Zone

Downward movement of water from the surface or near surface typically would pass through an unsaturated zone of soil, defined as the vadose zone, before proceeding to a predominantly saturated zone. Lateral movement of this water can also occur. The upper portion of the vadose zone is the soil water zone or the soils zone. The soils zone extends from the land surface to a depth corresponding to the predominant root depth for vegetation in the area, which typically is no more than a couple of feet at the WSS.

Because of local and seasonal variations in recharge and discharge, the vadose zone thickness is expected to vary locally, seasonally, and from year to year. A comparison of Figures 1-16 and 1-17 gives an indication of the seasonal variation of vadose zone thickness. Additional monitoring data will allow for a more accurate delineation of seasonal variation of groundwater levels as outlined in Section 2. Specific yield (effective porosity) in limestones, in zones with limited fracturing and solution cavities, can be assumed to range from <5 to 10%. Therefore, moderate precipitation events, perhaps in recharge areas southwest of the site can be responsible for seasonal variations in water levels as illustrated in Figures 1-16 and 1-17. An examination of cross sections in Figures 1-10 through 1-13 shows the groundwater elevations in the summer of 1986 as being typically 10 ft below the top of bedrock. The vadose zone thickness variation from more than 30 ft to more than 65 ft at different locations in the WSS is also governed, in part, by topographic and manmade features.

Also, the geological environment at the WSS exhibits complex saturated-unsaturated conditions occurring within the vadose zone. Saturated regions within the vadose zone (perched groundwater bodies) result from the presence of a lower hydraulic conductivity layer in a higher hydraulic conductivity formation.

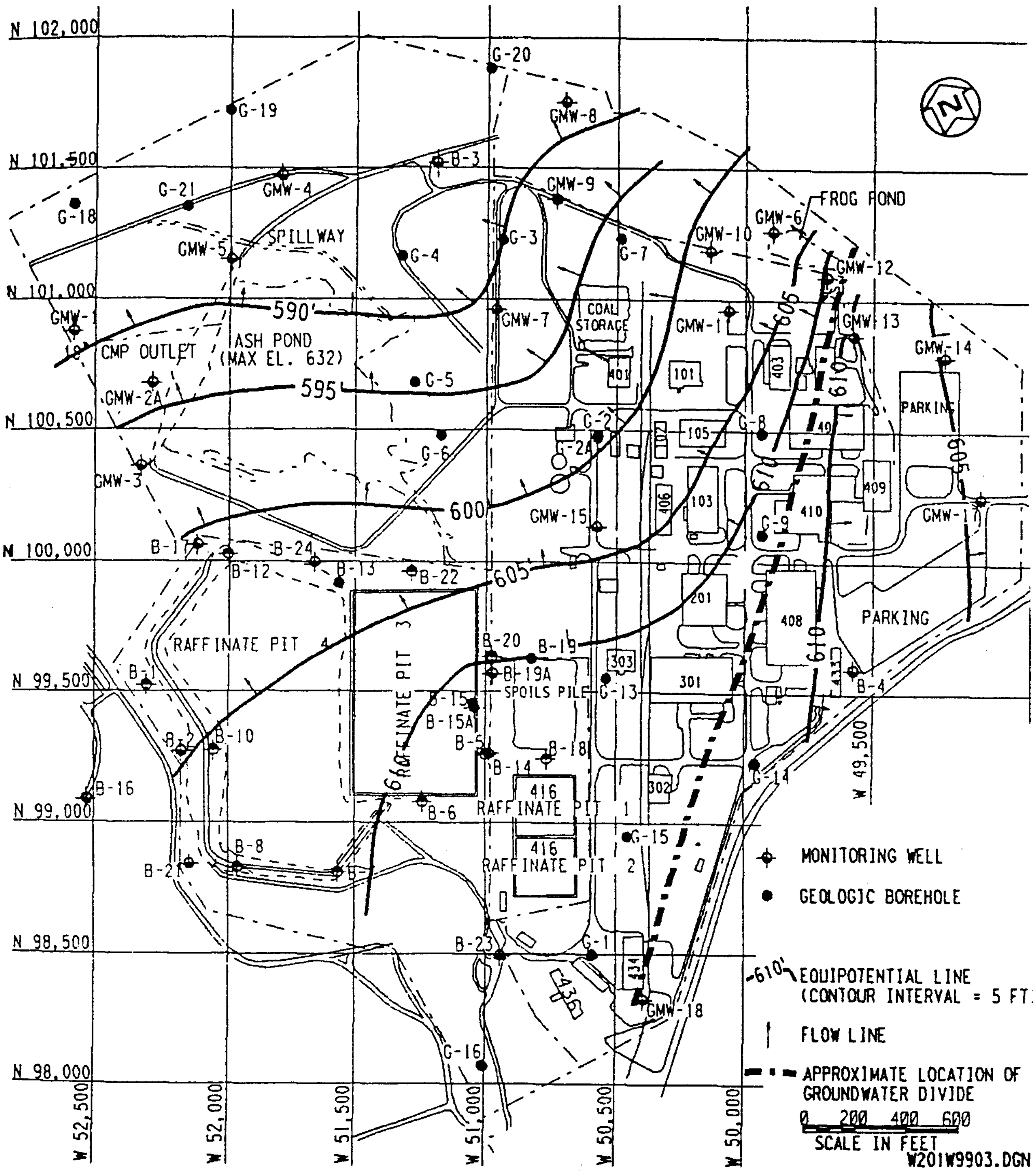


FIGURE 1-16

GROUNDWATER ELEVATIONS AND CONTOURS WSCP/WSRP

NOVEMBER 1986

SOURCE : BNI, 1987

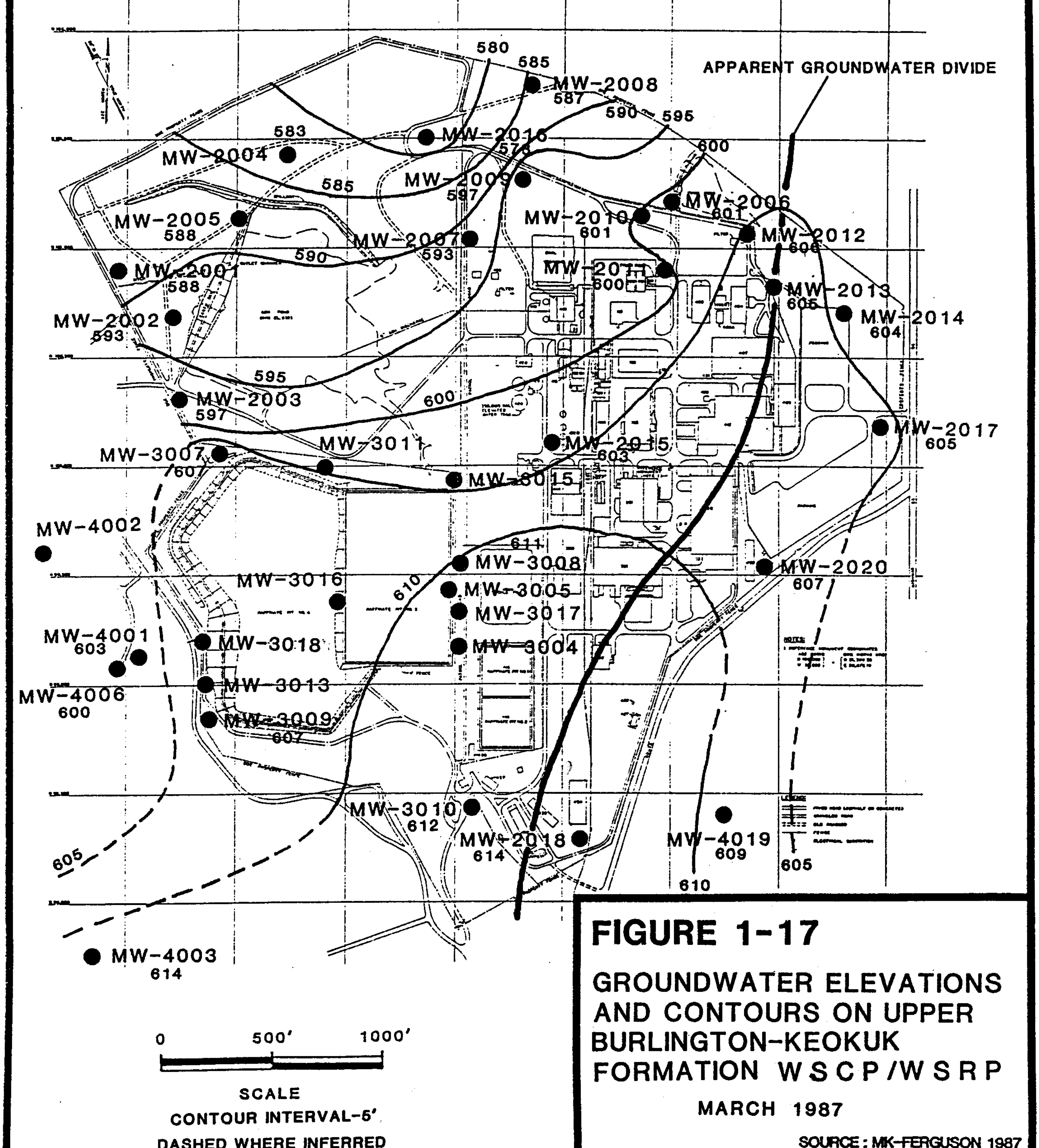


FIGURE 1-17

GROUNDWATER ELEVATIONS AND CONTOURS ON UPPER BURLINGTON-KEOKUK FORMATION WSCP/WSRP

MARCH 1987

SOURCE: MK-FERGUSON 1987

The result is the formation of discontinuous saturated lenses above the lower hydraulic conductivity clay layer, with unsaturated conditions existing both above and below these lenses.

Previous exploratory drilling investigations conducted at the WSS indicated areas of anomalously high groundwater elevations or perched groundwater in the vicinity of the raffinate pits (Lawrence Berkeley Laboratories, 1980, BNI 1984, and UNC Geotech July 1987). Fourteen observation wells and 10 vibrating-wire piezometers were installed in the overburden over the course of three investigations. Completion data for these installations is shown on Table 1-5. Wells were renumbered by WSSRAP staff along with bedrock monitoring wells at the beginning of WSSRAP efforts, prior to separation of bedrock aquifer and overburden monitoring programs. Wells to be used in further overburden studies are discussed in Section 2.4.

Of the 24 installations, 6 indicated saturated conditions during the original investigations. Pore-pressure measurements from Piezometers B-5 and B-22 indicated saturated conditions. Wells B-2 and B-14 originally penetrated saturated soils, although B-14 went dry near the end of the BNI investigation and has remained dry. Well W-2, installed by Lawrence Berkeley Laboratories, penetrates soils which are seasonally saturated. Well B-16 was installed in saturated residuum overlying bedrock on the Weldon Spring Training Area at a relatively remote location from the raffinate pits. Well B-15A, installed on the east berm of Raffinate Pit 3, was dry during the original investigation but has contained water continuously during WSSRAP efforts. Water level elevation in this well is approximately 630 feet, compared to a water level elevation of 611 feet in MW-3008 approximately 120 feet to the northeast, indicating significant, although perhaps localized mounding. Water level elevation in W-2, on the west side of Raffinate Pit 4 is approximately 612 feet, compared with a water level elevation of 607 feet in MW-3007 to the north and MW-3009 to the south, indicating a smaller degree of mounding

TABLE 1-5

OVERBURDEN WELL AND PIEZOMETER DATA SHEET
WELLS AND PIEZOMETERS INSTALLED DURING PREVIOUS INVESTIGATIONS

NEW WELL NUMBER	OLD WELL NUMBER(S)	APPROXIMATE COORDINATES NORTH	APPROXIMATE COORDINATES WEST	ELEVATION OF TOP OF CASING NGVD*	TOTAL DEPTH FT BGL**	CASING DIAMETER IN	SCREEN LENGTH FT
	B-1	99507	52283	N/A	18.5	N/A	0.5
	B-2	---	---	633.08	26.8	2	3.0
	B-5	99235	50977	N/A	18.8	N/A	0.5
	B-6	99050	51224	N/A	19.5	N/A	0.5
	B-7	98764	51596	N/A	21.3	N/A	0.5
	B-8	98750	51969	N/A	28.5	N/A	0.5
	B-10	99257	52044	N/A	23.8	N/A	0.5
	B-12	100003	51968	N/A	29.0	N/A	0.5
OMW-3503	B-14	99236	50965	655.62	21.8	2	5.0
	B-15A	99410	51021	665.66	32.0	2	5.0
MW 4006***	B-16	99014	52513	623.06	28.5	2	5.0
	B-18	99218	50750	N/A	23.4	N/A	0.5
	B-20	99597	50956	N/A	29.0	N/A	0.5
	B-22	99931	51266	N/A	13.0	N/A	0.5
	B-24	99965	51635	652.14	26.5	2	3.0
	W-1	**			33.0	4	
OMW-3504	(W-2) (MW-3018)	**			22.0	4	
	W-3	**			25.0	4	
	W-4				20.0	4	
	W-5				32.5	4	
	W-6				51.0	4	
	W-7				35.0	4	

* NGVD - Natural Geodetic Vertical Datum of 1929
** BGL - Below Ground Level
*** MW-4006 is included in the bedrock monitoring well network

in this area. Further studies will more closely examine hydrogeologic conditions at the residuum/bedrock interface. Additional investigations by BNI included conducting geophysical surveys which detected seismic velocity layers of 5000 ft/s at approximately 10 feet below ground surface in the areas within, beneath, and surrounding Raffinate Pit 3. This velocity is generally indicative of saturated conditions. Figure 1-18 presents a contour map of the surface of this 5000 ft/s layer and indicates a mounding effect from Raffinate Pit 3 (BNI 1984). Two shallow overburden monitoring wells were installed in July 1987 by UNC Geotech to investigate perched groundwater due to shallow seepage from the raffinate pits. One well, OW-3501, located immediately to the north of Raffinate Pit 1, indicated a shallow saturated zone approximately 1 foot below the surface. A similar installation (OW-3502) on the north side of Raffinate Pit 3 has remained dry since installation.

A total of 10 lysimeters were installed in 3 boreholes during the period July 7-10, 1987 during the course of radiologic site characterization by UNC Geotech Inc. These multiple lysimeter installations were planned as a preliminary assessment of contaminant transport by unsaturated flow. Locations were selected from examination of color aerial photographs on which areas of dark green vegetation indicated potential seepage of raffinate pit waters with high nitrate concentrations. Figure 1-19 presents the locations of the lysimeters installed by UNC Geotech. Results of analyses for inorganic constituents from soil pore-water samples obtained on Sept. 17, 1987 indicate elevated concentrations of nitrate, calcium, and sodium at all three locations. The sample containing the highest concentrations of these parameters, especially nitrate (8,976 mg/l), was obtained from lysimeter LY-3608 at a depth of 5.5 feet. The lysimeter is located north of Raffinate Pit 1 (Figure 1-19) in an area exhibiting saturated conditions near the surface. The analytical results coupled with the saturated

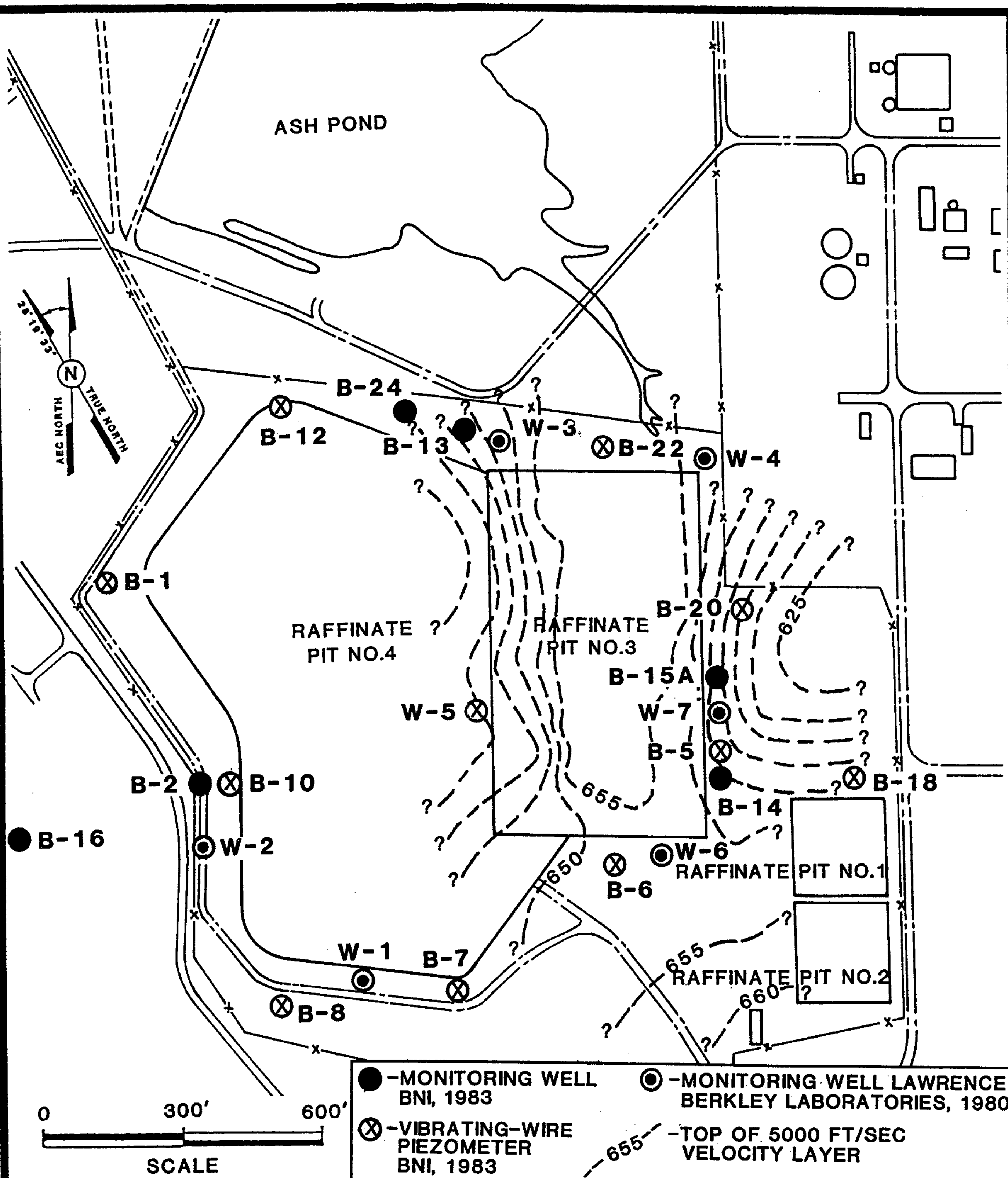


FIGURE 1-18

OVERBURDEN MONITORING WELLS AND PIEZOMETERS

INSTALLED DURING PREVIOUS INVESTIGATIONS
SOURCE : BNI, 1984

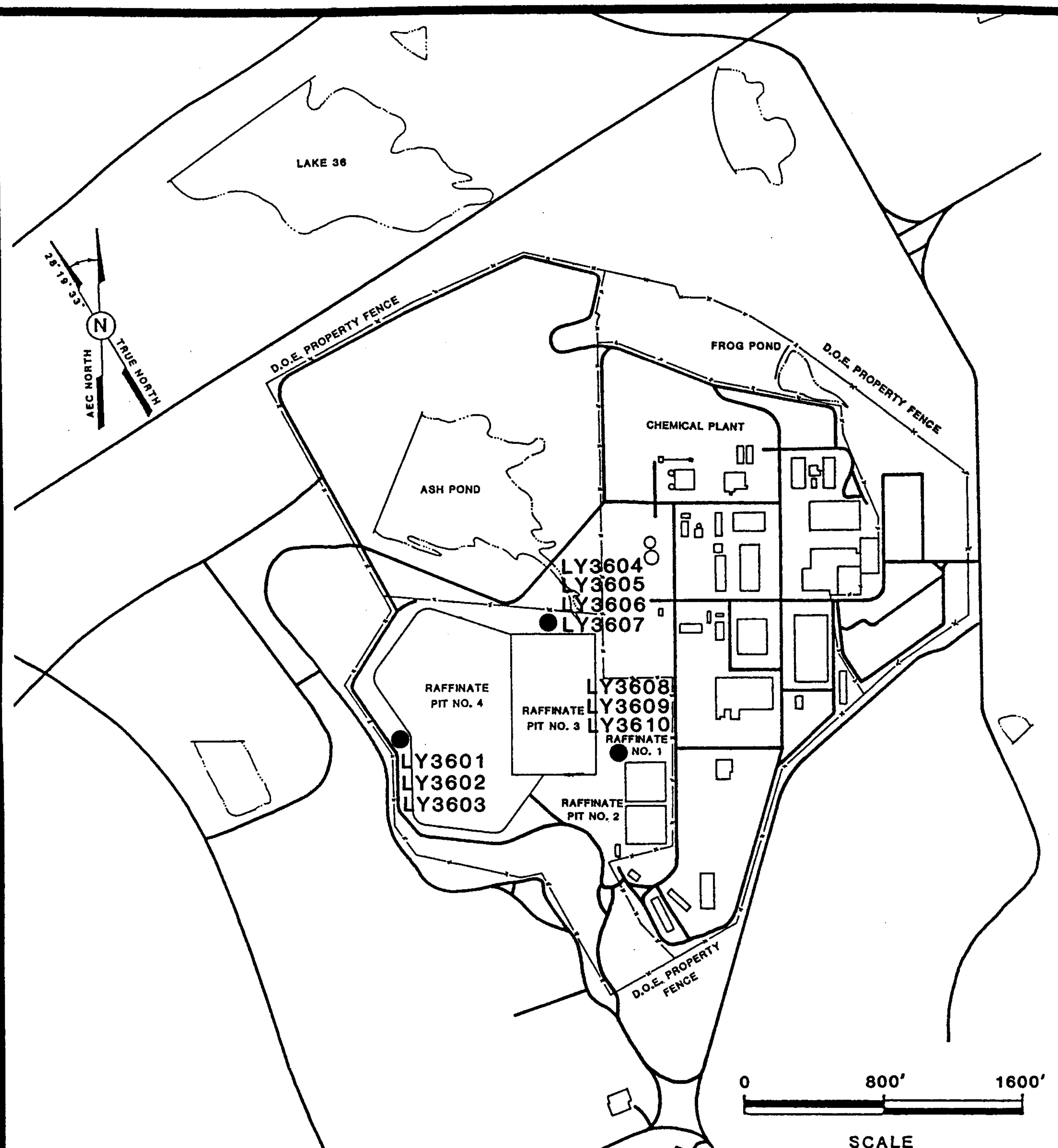


FIGURE 1-19

EXISTING LYSIMETER LOCATIONS

surface conditions indicate seepage is occurring from Raffinate Pit 1. Additional lysimeter monitoring points will be required in order to evaluate contaminant migration.

1.2.7 Hydrogeology

This section summarizes information available in existing reports related to the hydrogeology of WSS and adjacent areas. Information on groundwater occurrences and flow and their variations is presented along with a discussion of potential areas of recharge and discharge at the WSS and vicinity. Quantitative information on background water quality and an evaluation of the adequacy of the data are also presented.

1.2.7.1 Groundwater Occurrences

As discussed in previous sections, the land surface slopes outward from the site. The sediments consist of unconsolidated material overlying slightly dipping bedrock formations of varying complexity and importance.

The USGS delineates three principal aquifer systems in the general area: the alluvial aquifers, the shallow bedrock aquifer system, and the deep aquifer system (Kleeschulte and Emmett, 1986). The alluvial aquifers include the saturated sands, gravels, and silts in the alluvium of the Missouri and Mississippi rivers and the alluvium of tributary creeks where significant groundwater yields can occur. The shallow bedrock system primarily consists of saturated rock of Mississippian and Devonian age which includes formations at the WSS from the Burlington/Keokuk Limestone down through the Bushberg Sandstone. At the WSS the shallow bedrock aquifer is subdivided into upper and lower zones. The upper zone is the weathered and fractured portion of the Burlington/Keokuk Formation. The deep aquifer system primarily consists of Ordovician and Upper Cambrian saturated rocks which include sediments from the St. Peter

Sandstone down through the Potosi Dolomite. The shallow and deep aquifers are separated by a leaky confining layer from the base of the Bushberg Sandstone down through the Joachim Dolomite (Kleeschulte and Emmett, 1986). Individual units or zones in this layer may be classified as low yielding aquifers (Kleeschulte and Emmett, 1986).

The upper zone of the shallow bedrock aquifer, as defined by the USGS, is the main emphasis and concern at the site for several reasons. First, it is in close proximity to contaminant sources. Second, it is weathered, fractured, and of higher hydraulic conductivity than deeper, unweathered zones. Finally, it is the zone most likely to permit contaminant migration.

Kleeschulte and Emmett (1986) present regional maps of the shallow and deep bedrock aquifer potentiometric surfaces. These maps are reproduced here in Figures 1-20 and 1-21. The shallow aquifer data, Figure 1-20, show a groundwater divide running approximately E-W through the vicinity of the raffinate pits monitoring wells (represented by the four dots within the delineated Army Property). The potentiometric surface elevations ranged from more than 650 ft near the west boundary of the original DOA property to less than 425 ft near the Mississippi River.

Figures 1-16 and 1-17 give site-specific groundwater levels taken from monitoring wells completed primarily in the upper portion of the Burlington/Keokuk Formation (BNI, 1987; MKF, 1987b). The monitoring well numbering system shown in Figure 1-16 differs from that of Figure 1-17. However, for the most part, the same wells have been used in providing data for the preparation of both maps. Both maps indicate a groundwater divide trending approximately SW-NE across the southeastern portion of the WSS site. The detailed shapes of the two sets of contours are different but the general trend is the same. The differences are due to the use of different monitoring wells, the seasonal and

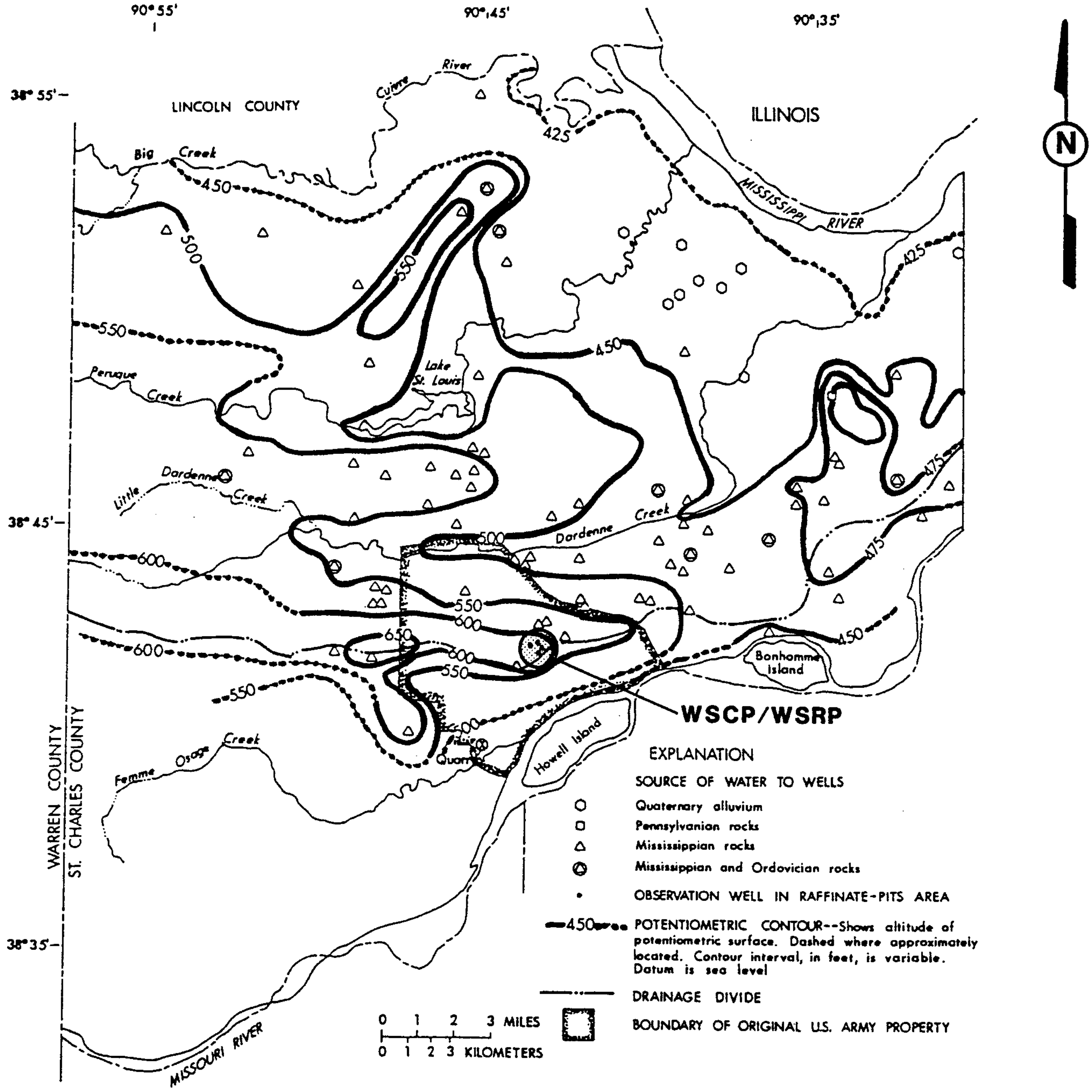


FIGURE 1-20

POTENTIOMETRIC SURFACE OF THE SHALLOW BEDROCK AQUIFER, SUMMER 1984 (MISSISSIPPIAN AND DEVONIAN SEDIMENTS)

SOURCE : KLEESCHULTE & EMMETT, 1986

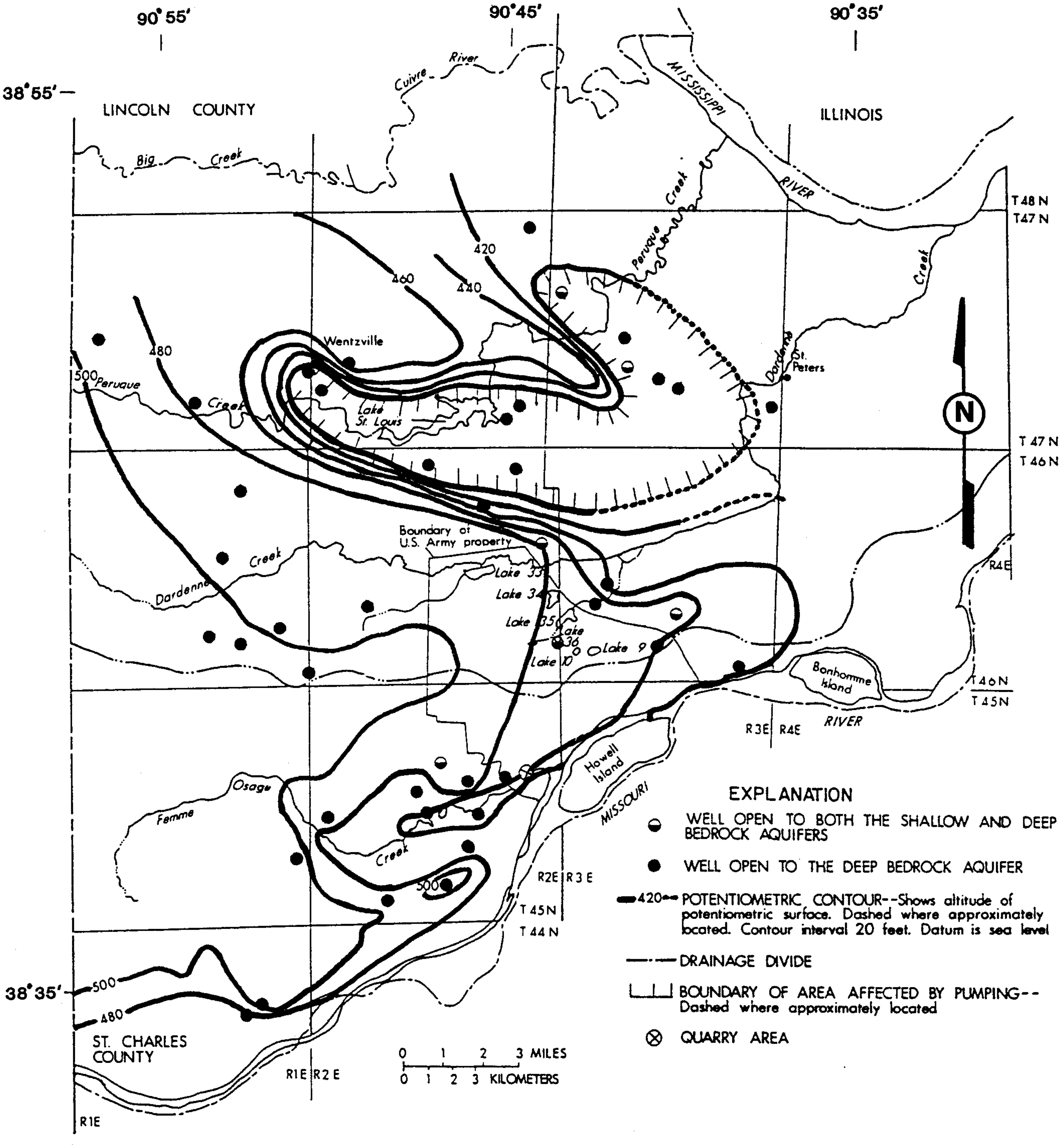


FIGURE 1-21

POTENTIOMETRIC SURFACE OF THE DEEP BEDROCK AQUIFER, SUMMER 1984

SOURCE : KLEESCHULTE & EMMETT, 1986

annual variations represented by the data, and the differences in interpretation by the individual map preparers. The range in elevations is from more than 610 ft to less than 580 or 590 ft, depending on the map. Inspection of the cross sections in Figures 1-11 through 1-13 indicates that depths to groundwater vary from about 30 to 65 ft. BNI indicates a minimum depth of 18-20 ft below Raffinate Pit 4 (BNI, 1984c).

Alluvial aquifers are found along the Missouri and Mississippi rivers and major tributaries (BNI, 1987). Groundwater is present at some locations in the unconsolidated formations in the vicinity of the site. On site, groundwater is present in the overburden in areas bordering Raffinate Pits 3 and 4. This indicates that these surface-water impoundments are leaking and forming a groundwater mound in the immediate area surrounding these pits.

Groundwater in the "deep bedrock aquifer system" is represented by the regional map (Figure 1-21) of Kleeschulte and Emmett. For reference, note the boundary of the U.S. Army Property compared to that in Figure 1-20. A groundwater divide exists just north of the WSS with a large groundwater depression 4 or 5 miles further north of the divide. The aquifer system represented in Figure 1-21 includes the Ordovician shale, limestone, dolomite, and sandstone from the Maquoketa Shale to the base of the Potosi Dolomite. The approximately 350-ft-thick upper portion of the system which extends to the Joachim Dolomite is less permeable than the approximately 1000-ft-thick lower portion and tends to form a confining layer (Kleeschulte and Emmett, 1986).

Lateral boundaries of aquifer systems in the vicinity of the site are not fully delineated in the available reports. Groundwater discharges can be observed locally from the bedrock aquifer in or near gullies, at least intermittently, as seeps and springs (Dean, 1984a, 1984b, 1985). Figure 1-22 shows the locations of local springs. This map is also presented in Section 2.3.2.1

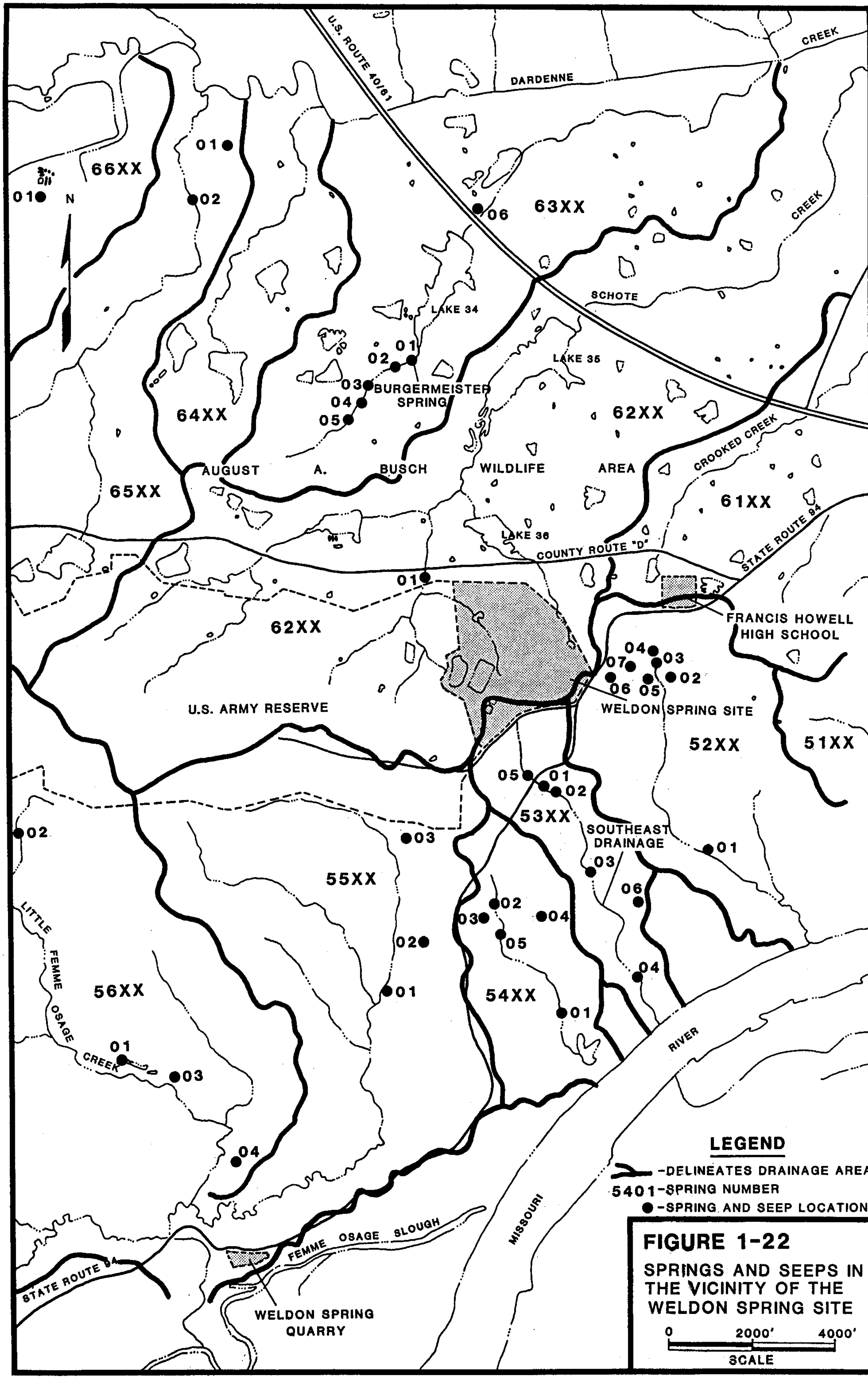


FIGURE 1-22
SPRINGS AND SEEPS IN THE VICINITY OF THE WELDON SPRING SITE

(Figure 2-6) along with a description of the WSSRAP numbering system for these springs. During the summer and fall of 1987 a complete reconnaissance survey of the area surrounding the WSS was performed to locate springs and seeps which are potentially affected by the WSS. This survey was performed by Missouri Department of Natural Resources (MDNR) and WSSRAP geologists. A total of 30 springs and seeps were identified and located on USGS 7.5-minute topographic maps. Fishel and Williams (1944) indicate that Dardenne Creek Valley intercepts flow from the shallow bedrock system. Hence, the extent of the upper and lower zones of the shallow aquifer are partially defined in the area.

There are boundaries tending to inhibit vertical transfer of water. These include the upper 350-ft-thick portion of the deep bedrock aquifer system described above, and the lower portion of the Burlington/Keokuk as previously discussed (see Section 1.2.4). Also, the Meramecian Series, where present regionally, may be a confining layer for water in the lower portion of the shallow bedrock aquifer (Kleeschulte and Emmett, 1986). Units that may minimize vertical movement of groundwater below the Burlington/Keokuk and above the Maquoketa Shale are not defined.

Porosity of the bedrock aquifers at the site is a combination of primary and secondary porosity. Primary porosity is that portion of the bedrock void space that is present within the matrix of the rock itself. Secondary porosity consists of fractures, solution channels, and fine interconnected fractures in the limestone bedrock (MKF, 1987b). The Burlington/Keokuk Formation and the Fern Glen Limestone may be deeply weathered in outcrop areas and may transmit water primarily through solution openings and joints (Kleeschulte and Emmett, 1986).

Porosity in the deep bedrock aquifer includes solution-enlarged joints in the Kimmswick Limestone (Kleeschulte and Emmett, 1986) and primary porosity in the St. Peter Sandstone. The types of porosity in the other bedrock aquifer formations are uncertain.

1.2.7.2 Groundwater Movement

Groundwater flow in the upper, weathered portion of the Burlington/Keokuk Formation occurs in two distinct flow regimes: Darcian flow and conduit flow. Darcian flow occurs through the fine fractures of the formation, which comprise an equivalent porous medium. Conduit flow occurs where subsurface groundwater pathways have developed selectively within the fracture network. These conduits are generally dendritic or trellised. Conduits typically discharge into springs, seeps or other surface water bodies such as streams, rivers or lakes. Darcian flow is dispersive, while flow in conduit systems is convergent (Quinlan and Ewers, 1985).

Figure 1-17 implies the general direction of groundwater movement in the shallow bedrock aquifer at the WSRP/WSCP. For a continuous medium which is isotropic with respect to hydraulic conductivity, the groundwater flow direction would be at right angles to the contours. However, for an anisotropic medium, such as one with conduit flow, the flow could be oblique to contours. The general flow directions for the discussion below will be estimated based on flow in an isotropic continuous medium.

Groundwater flow directions in the upper Burlington/Keokuk Formation are defined by the position and orientation of the groundwater divide. Referring to Figure 1-17, the flow is to the north from most of the WSS; in the southeastern portion of the site the flow is to the southeast or east. The regional potentiometric surface for the shallow bedrock aquifer (Figure 1-20) shows a similar pattern, indicating opposing flow directions depending on location relative to the divide.

Fishel and Williams (1944) described red water leakage from a lagoon located 100 yards east of Frog Pond and its detection at two springs north and northwest of the WSS (see Section 1.2.8).

The Missouri Department of Natural Resources further defined groundwater movement through subsurface water tracing dye studies, conducted in 1983, 1984, and 1985 (Dean 1983, 1984a, 1984b, 1985). Dean's findings are summarized below.

Rhodamine WT dye and fluorescein dyes were injected into three drill holes (B-3, now MW 2016, B4, now MW 2020, and B17, now MW 3007) in February and March 1983. No positive identification of water tracing dyes was detected at charcoal packet monitoring locations placed, primarily in stream channels, at locations to the North and South of the WSRP/WSCP.

Rhodamine WT dye was placed into surface drainage west of Raffinate Pit 4 of February 1984. This drainage is an unnamed tributary of Schote Creek draining to Lake 35. Dye was detected in packets placed at five monitoring locations:

1) At Burgermeister spring
2) At a resurging sink immediately south of Burgermeister spring,
3) At a spring south of Pond C upstream of Lake 34
4) At a creek channel 50 ft west of 2 (above) and downstream of 3 (very weak trace)
5) In the watershed just upstream of the tail waters of Lake 35 (very weak trace - negative on Feb. 17, 1984).

Dean concluded that plant area runoff trending north via the drainage west of Raffinate Pit 4 can be expected to flow underground and emerge at or in the vicinity of Burgermeister Spring, a straight line flow distance of approximately 6500 feet. Time of travel was not accurately determined but initial arrival was estimated to be 48-72 hours and would be dependent upon precipitation events.

In June 1984, Rhodamine WT dye was injected at the process sewer outfall (Southeast Drainage Easement). Dye was detected at two springs (SP5301 and SP5303) along the drainage easement toward the Missouri River, approximately 0.25 and 0.50 miles downstream, respectively. This test established flow connection to the south of the groundwater divide.

In March 1985, Rhodamine WT dye was introduced into a sink in the Ash Pond outflow stream west of DOE property. With the detection of dye traces at the Burgermeister Spring and vicinity, a subsurface connection was established between the outflow stream drainage downstream of Ash Pond and the Burgermeister Spring area.

Additional dye tracing tests are being conducted at this time. Data received from these tests will be presented in subsequent reports.

Flow directions in the deep bedrock aquifer system are shown on Figure 1-21. Flow in the vicinity of the site in 1984 was to the northeast and southeast. Flow to the north eventually enters the groundwater depression produced by pumping of municipal wells in Wentzville and O'Fallon. The eventual discharge point(s) of flow to the south is unknown.

The potential for vertical movement of groundwater is implied by a comparison of groundwater levels in Figures 1-20 and 1-21. In 1984, there was an approximate 125-ft head differential between the deep and shallow groundwater aquifers in the vicinity of the site, with the deep aquifer system having the lower levels. Groundwater will tend to move downward with this head differential. However, the effective hydraulic conductivity between the two aquifers is unknown.

Recharge and discharge locations and quantities typically have an effect on groundwater movement. Recharge to alluvial aquifers occurs from precipitation on the alluvium; from flooding that causes surface water to go into bank storage; from flows from contiguous bedrock aquifers; and from induced flow into the aquifer as a result of groundwater pumping (Kleeschulte and Emmett, 1986). Discharge from alluvial aquifers occurs from natural discharge via evapotranspiration (through phreatophytes), from recession periods which result in return flow from bank storage, from wells tapping the aquifer, and from discharges into the contiguous bedrock. Recharge and discharge from alluvial aquifers near the site potentially affect the aquifers at the site, as they can affect the subsurface flow between aquifers.

Discharge and recharge sources similar to those for the alluvial aquifer apply to the shallow bedrock aquifer at the WSS and vicinity with the addition of recharge from losing streams and discharge to springs. Discharge/recharge mechanisms for the deep bedrock aquifer include: recharge from precipitation directly on the area where the deep bedrock aquifer outcrops or is overlain by permeable soils; recharge from losing streams which penetrate the aquifer; downward leakage from the shallow bedrock aquifer; extraction by wells tapping the aquifer; evapotranspiration, and seepage to springs and streams (Kleeschulte and Emmett, 1986).

Groundwater usage in the Weldon Spring area has been summarized by BNI (1987). The principal groundwater extraction areas in the region of the site are the St. Charles County well field (located in the Missouri River flood plain approximately 5 miles southwest of the site), and the cities of Wentzville, O'Fallon, and St. Peters. St. Charles County and St. Peters extract groundwater from the alluvial aquifer while the cities of Wentzville and O'Fallon withdraw groundwater from the deep bedrock aquifer. The city of St. Peters formerly utilized wells in the deep bedrock aquifer. The St. Charles County well field produces approximately 10.5 mgd, and in 1985 Wentzville, O'Fallon, and St. Peters extracted 0.59, 1.22, and 2.9 mgd, respectively (Kleeschulte, 1988). The groundwater contour maps presented previously reflect the composite effect of discharges and recharges to the aquifer systems plus the hydraulic properties.

Figure 1-21 specifically identifies a groundwater depression in the deep bedrock aquifer that is a result of groundwater pumping.

There are also domestic wells being utilized in the vicinity of the site. On June 5, 1984 the St. Charles Countians Against Hazardous Waste (SCCAHW) completed a groundwater inventory of wells and springs in St. Charles, Defiance, Weldon Spring, St. Peters, Wentzville, O'Fallon, Augusta, and New Melle. The study was representative of the combined efforts of the St. Charles County Administrative Court, the Missouri Division of Health, the Missouri Department of Natural Resources (MDNR), the Missouri Department of Conservation, and SCCAHW. Figure 1-23 (in pocket) represents a compilation of private well information received from SCCAHW and recently acquired data forwarded by the USGS.

The map shown on Figure 1-23 covers the area used for the WSSRAP Groundwater Classification Study currently being prepared (October 1988). The well numbers shown on the map are those used in listings of private wells by USGS and SCCAHW. Many private wells are no longer in use and have been omitted from this map. Wells located within the present boundaries of the Busch Wildlife and Weldon Spring Wildlife areas are assumed to have been abandoned around 1941, when private properties were sold to the U.S. Government for the WSOW. These wells, which have recorded locations but no record of water samples or water-level measurements, have been omitted. It is likely that many private wells in residential areas are no longer in use due to expansion of public water systems. Future WSSRAP efforts will seek to verify locations and usage of private wells.

Table 1-6 presents information pertaining to well yields in the area around the WSS bounded by the Mississippi River (10-15 miles north), and the Missouri River (3 to 4 miles to the south and east of the site). The table lists the major aquifers which supply municipalities, communities, farms and industries. It also illustrates which productive zones are more susceptible to

TABLE 1-6 DOMESTIC WELL DATA
WELLS LISTED BY USGS

No. (See Map)	Latitude (Degrees-Minutes-Seconds)	Longitude (Degrees-Minutes-Seconds)	USGS Location	Altitude of Land Surface (ft above sea level)	Well Depth (ft)	Casing Depth (ft)	Altitude of Water Level (ft above sea level)	Formations Open To Well(1)
1	38 39 02	90 47 15	T45N R02E SWSWSW 15	560	250	44	--	DCRH-STRP
2	38 39 10	90 44 17	T45N R03E SENWSW 18	460	114	--	445	--
3	38 39 57	90 47 40	T45N R02E NESWSW 10	725	485	20	624	MISS-STPR
5	38 40 08	90 43 52	T45N R03E NWNWSE 7	615	535	55	515	JCHM-STPR
6	38 40 45	90 48 20	T45N R02E SWSWSE 4	732	505	66	642	BRLG-STPR
9	38 41 35	90 39 16	T46N R03E SWSWSE 35	490	702	169	460	ALVM-STPR
10	38 41 38	90 38 51	T46N R03E SENESE 35	580	790	--	400	OSGE-JLNM
11*	38 41 39	90 48 42	T46N R02E SESWSW 33	740	--	--	695	MISS
12*	38 41 44	90 49 53	T46N R02E NESWSW 32	740	210	90	647	MISS
14	38 42 01	90 48 18	T46N R02E SWSWNE 33	690	275	--	630	BRLG-KMCK
15	38 42 03	90 47 28	T46N R02E SWSWNW 35	--	622	--	--	MISS-STPR
16*	38 42 06	90 42 51	T46N R03E NESENW 32	652	275	--	595	KKKB-FRGL
18	38 42 19	90 37 52	T46N R03E SWSESE 25	620	811	359	460	WRSW-EVRN
19	38 42 19	90 37 52	T46N R03E SWSESE 25	640	771	--	--	WRSW-STPR
20*	38 42 21	90 44 25	T46N R02E NENENE 36	620	330	84	324	KKKB-KMCK
21*	38 42 28	90 43 30	T46N R03E SWSESE 30	637	--	--	587	MISS
22*	38 42 29	90 43 30	T46N R03E NWSESE 30	640	260	--	569	KKKB
24*	38 42 40	90 38 54	T46N R03E NWNESE 26	643	300	--	462	MISS
25	38 42 41	90 39 49	T46N R03E NWNWSW 26	595	350	--	--	WRSW-BBRG
26*	38 42 47	90 41 15	--	540	--	--	--	--
27*	38 42 48	90 42 14	T46N R03E SESENE 29	573	--	--	537	MISS
28*	38 42 55	90 42 21	T46N R03E NWSENE 29	570	215	41	532	KKKB-FRGL
29*	38 42 57	90 48 30	T46N R02E SWSENW 28	622	265	84	592	MISS
30*	38 42 58	90 48 16	T46N R02E SWSWNE 28	628	185	--	583	MISS
31	38 42 59	90 38 51	T46N R03E SESENE 26	590	375	--	--	WRSW-CHUT
32*	38 43 01	90 40 06	T46N R03E SWNENE 27	597	0	--	553	WRSW-KKKB
33*	38 43 01	90 40 28	T46N R03E SENENW 27	542	125	41	519	KKKB
36	38 43 13	90 41 35	T46N R03E NENWNE 26	555	255	--	498	WRSW-FRGL
37*	38 43 19	90 45 54	T46N R02E NENWNE 26	595	360	--	535	MISS
38*	38 43 19	90 48 16	T46N R02E SESWSE 19	612	105	62	568	KKKB
39	38 43 23	90 43 38	T46N R02E SWSESW 21	585	300	75	510	WRSW-KDRK
40*	38 43 24	90 48 32	T46N R02E SWSESW 21	650	228	--	589	MISS
41*	38 43 24	90 48 32	T46N R03E SWSWNE 23	600	275	40	442	SLEM-KKKB
42	38 43 40	90 49 53	T46N R02E SENWSW 20	625	325	--	525	KKKB-DCRU

* SOURCE OF DATA = 1984 SURVEY

(CONTINUED)

TABLE 1-6 DOMESTIC WELL DATA (cont.)

No. (See Map)	Latitude (Degrees-Minutes-Seconds)	Longitude (Degrees-Minutes-Seconds)	USGS Location	Altitude of Land Surface (ft above sea level)	Well Depth (ft)	Casing Depth (ft)	Altitude of Water Level (ft above sea level)	Formations Open To Well(1)
43*	38 43 45	90 37 39	T46N R03E NESENE 24	487	150	40	470	WRSW-KKKB
45	38 43 47	90 44 06	T46N R03E SESWNW 19	545	125	48	465	KKKB
46	38 43 48	90 44 12	T46N R03E SWSWNW 19	550	220	60	--	OSGE
47*	38 43 48	90 44 12	T46N R03E NWSWNW 19	551	305	45	500	KKKB-BBRG
48*	38 43 51	90 44 07	T46N R03E NESWNW 19	545	--	--	495	MISS
49*	38 43 53	90 49 47	T46N R02E SESWNW 20	647	325	55	577	KKKB-KMCK
50*	38 43 56	90 39 25	T46N R03E SWNENW 23	559	225	28	481	SLEM-KKKB
51*	38 43 58	90 42 30	T46N R03E NWNWNE 20	531	300	22	476	KKKB-BBRG
52*	38 43 59	90 44 01	T46N R03E SWNENW 19	518	--	--	478	MISS
53*	38 44 02	90 38 42	T46N R03E SESESE 14	555	560	67	456	WRSW-KMCK
55*	38 44 20	90 39 55	T46N R03E SESESE 15	485	200	52	466	WRSW-KKB
56	38 44 36	90 39 12	T46N R03E NWSWNE 14	520	235	--	--	KKKB
57	38 44 36	90 44 28	T46N R02E SWSENE 13	545	690	205	495	OSGE-STPR
58*	38 44 40	90 38 20	T46N R03E NWSENW 13	498	100	--	470	MISS
59*	38 44 47	90 39 10	T46N R03E SWNWNE 14	515	165	41	468	KKKB
60*	38 44 50	90 46 08	T46N R02E NESENW 14	555	205	46	531	KKKB-FREL
61*	38 44 56	90 43 07	T46N R03E NWNWNW 17	553	130	43	510	KKKB
62	38 43 34	90 43 51	--	485	--	--	--	--
71	38 43 50	90 43 40	--	560	230	--	--	--
72	38 43 50	90 43 50	--	485	630	--	--	--
73	38 43 52	90 43 51	--	525	111	--	--	--
75	38 43 13	90 44 33	--	590	107	--	--	--
80	38 41 13	90 40 57	--	460	--	--	--	--

* SOURCE OF DATA = 1984 SURVEY

(1)

ALVM, alluvium
PENN, Pennsylvanian System, exact formation unknown
STSL, St. Louis Limestone
WRSW, Warsaw Formation
KKKB, Keokuk and Burlington Limestones
FRGL, Fern Glen Limestone
CHUT, Chouteau Limestone
MISS, Mississippian System, exact formation unknown
BBRG, Bushberg Sandstone of Sulphur Springs Group
SSPG, Sulphur Springs Group
KMCK, Kimmswick Limestone
DCRH, Decorah Formation
PLTN, Plattin Limestone
JCHM, Joachim Dolomite
STPR, St. Peter Sandstone
PWLL, Powell Dolomite
CTTR, Cotter Dolomite
JFRC, Jefferson City Dolomite
RBDX, Roubidoux Formation
GSCD, Gasconade Dolomite
ODVC, Ordovician System

contamination by vertical migration of contaminants and shows the position of shales and zones of low hydraulic conductivity that provide a barrier to vertical groundwater flow (as a confining layer). Table 1-6 was compiled from USGS data (Kleeschulte, 1988).

Hydraulic or aquifer parameters of potential importance to the WSS assessment of groundwater and contaminant movement are hydraulic conductivity (permeability), transmissivity, storativity, porosity, and dispersivity. Aquifer tests made on wells tapping the Kimmswick to the St. Peter in St. Charles County gave specific capacities of 0.07 to 0.25 gpm/ft of drawdown (Kleeschulte and Emmett, 1986). Wells penetrating deeper formations had specific capacities ranging from 0.53 to 2.64 gpm/ft of drawdown (Kleeschulte and Emmett, 1986). No estimates of transmissivities or hydraulic conductivities of these zones are available from field tests.

Hydraulic characteristics of the overburden at the WSS were also evaluated and discussed in the BNI, November 1984, and July 1987 reports. The upper few feet of overburden (mostly topsoil) are poorly drained. The materials underlying the topsoil are unsaturated. Disturbed and undisturbed samples of the major overburden units were submitted to a laboratory for soil testing. The hydraulic conductivities and moisture content of both dike fill and foundation materials were determined. The hydraulic conductivity values are generally low and range from 1.6×10^{-9} cm/s (4.5×10^{-6} ft/day) to 3×10^{-6} cm/s (8.5×10^{-3} ft/day). Hydraulic conductivity values for the silty clays and clayey silts are the highest measured. The geometric mean of the test results is 1.3×10^{-7} cm/s (3.7×10^{-4} ft/day). The moisture content of the samples ranged from 15 to 30%, indicating the materials are unsaturated. Test results for the clay materials obtained from a depth of about 3 m (10 ft) indicate a hydraulic conductivity range from 1.7×10^{-8} cm/sec

(4.82×10^{-5} ft/day) to 6.4×10^{-9} cm/sec (1.81×10^{-5} ft/day). Some laboratory test results for overburden samples from the site are summarized in Table 1-2. These indicate specific yields ranging from 1% to 12%. Borehole hydraulic conductivity test results for the overburden; and unsaturated and saturated bedrock are summarized in Table 1-7. These show hydraulic conductivities for unsaturated materials on the order of 10^{-3} to 10^{-2} cm/sec. Some of the results are also given on Figures 1-11 through 1-13 where locations of the test intervals are indicated. The types of tests were constant head, double and single packer pressure tests (BNI, 1987). Details of the specific testing procedures employed are not given.

The mean hydraulic conductivity in the weathered saturated zone was on the order of 10^{-3} cm/sec with considerable variation from the mean value; hydraulic conductivity in the slightly weathered to fresh bedrock zone averaged near 10^{-6} cm/sec with a variation of approximately one order of magnitude.

Comparison of hydraulic conductivity values in the weathered and unweathered portions of the bedrock indicate that values in the unweathered bedrock are three orders of magnitude lower than the weathered bedrock. The results indicate that the bedrock is of variable hydraulic conductivity in the horizontal plane and generally becomes less permeable with depth, due to decreased weathering and associated solution activity (BNI, July 1987).

BNI developed some estimates of hydraulic gradients and average interstitial velocities (1987). Referring to Figure 1-16, a range of hydraulic gradients exists at the site from zero at the groundwater divide to approximately 0.05 near Frog Pond. BNI estimates an average interstitial groundwater velocity of 0.04 ft/day, with an effective porosity of 30%, and a low hydraulic conductivity of 8.9×10^{-5} cm/sec (1987). Walton (1985) presents effective porosity values for limestones ranging from 1% to 24%. Assuming the above aquifer parameters, and applying more

TABLE 1-7
BOREHOLE HYDRAULIC CONDUCTIVITY TEST DATA FOR
UNSATURATED AND SATURATED BEDROCK
(BNI, 1987)

UNSATURATED BEDROCK		**SATURATED BEDROCK**	
Test on overburden/rock interface:		Tests on weathered, fractured bedrock:	
Number of Tests	= 4	Number of Tests	= 22
Depth Range	= 29.0 to 41.5 ft	Depth Range	= 30.1 to 77.7 ft
Mean	= 3.7×10^{-2} cm/sec [1]	Mean	= 1.6×10^{-3} cm/sec
Standard Deviation	= $\pm 4.3 \times 10^{-2}$ cm/sec [1]	Standard Deviation	= $\pm 2.8 \times 10^{-3}$ cm/sec
Test on weathered, fractured bedrock:		Tests on slightly weathered to fresh bedrock:	
Number of Tests	= 10	Number of Tests	= 5
Depth Range	= 23.0 to 66.7 ft	Depth Range	= 52.0 to 76.0 ft
Mean	= 2.7×10^{-3} cm/sec [1]	Mean	= 5.7×10^{-6} cm/sec
Standard Deviation	= $\pm 2.0 \times 10^{-3}$ cm/sec [1]	Standard Deviation	= $\pm 6.5 \times 10^{-6}$ cm/sec

[1] Numbers shown are statistics given in Table 8-1 of the reference.
Use of the individual values in Table 8-1 gives slightly different statistics than presented.

realistic effective porosity values of 5%, 10% and 20%, interstitial velocities of 0.25, 0.13 and 0.06 feet per day respectively are estimated. Many components of the hydrogeologic model are to be refined, e.g., recharge areas, aquifer parameters, surface run-off, groundwater levels, geology, and geochemistry, and a fuller understanding of the regime will occur with the acquisition of additional data under this plan. Velocity estimates, however, are based on the assumptions that the aquifer behaves as an equivalent porous medium. Groundwater flow velocities along preferential flow paths, such as along larger fracture openings or along solution channels, could be much higher. With a definition of time of contaminant release, these data and calculations can be used to estimate and predict rate of contaminant movement. Conversely, with a definition of the contaminant plume and a knowledge of rate of contaminant migration, possible sources can be delineated.

Seasonal variations of groundwater elevation are apparent from an examination of available groundwater level measurements. Table 1-8 gives three sets of measurements for the uppermost aquifer, two taken by BNI in 1986 approximately four months apart (BNI, 1987) and one taken by MKF in early 1987 (MKF, 1987b). The locations of the monitor wells are shown in Figure 1-16. The measurements represent three different seasons. Wells GMW-7, GMW-8, GMW-12, GMW-13, B-3, B-17, and B-19A exhibited changes in groundwater elevations of almost 2 ft to more than 7 ft for the time period represented. There was no consistent trend in the changes throughout the area.

1.2.7.3 Groundwater Quality Aspects

Water quality of the different aquifer systems is discussed by Kleeschulte and Emmett (1986). Water from alluvial aquifers is predominantly a calcium bicarbonate type, typically with high hardness and iron concentrations. The total dissolved solids (TDS) concentration is variable.

TABLE 1-8

GROUNDWATER ELEVATIONS (from BNI, 1987; MKF, 1987b)

NEW Well Number	OLD Well Number	Elevations in ft above MSL 7/24-30/86	11/01/86	3/20/87
MW-2001	GMW-1	588.86	589.15	588.55
MW-2002	GMW-2A	593.71	594.13	593.35
MW-2003	GMW-3	597.98	597.92	597.94
MW-2004	GMW-4	584.56	583.97	583.73
MW-2005	GMW-5	588.26	588.23	588.95
MW-2006	GMW-6	601.54	601.85	601.00
MW-2007	GMW-7	590.36	590.26	593.20
MW-2008	GMW-8	585.98	585.91	587.63
MW-2009	GMW-9	597.96	597.81	597.51
MW-2010	GMW-10	600.46	600.85	601.03
MW-2011	GMW-11	600.72	600.80	600.57
MW-2012	GMW-12	610.43	612.12	606.80
MW-2013	GMW-13	605.26	607.98	605.82
MW-2014	GMW-14	604.45	604.25	604.53
MW-2015	GMW-15	603.99	603.54	603.00
MW-2016	GMW-17	605.51	604.85	605.28
MW-2017	GMW-18	615.43	614.80	614.94
MW-2018	B-3	580.41	574.49	578.18
MW-2019	B-4	607.92	607.60	607.38
MW-2020	B-17	599.61	600.42	607.67
MW-2021	B-19A	608.70	610.84	611.63
MW-2022	B-21	607.77	607.22	607.53
MW-2023	B-23	612.84	612.23	612.14

Water quality of the shallow bedrock aquifer in St. Charles County varies from a calcium magnesium bicarbonate type to a sodium sulfate, bicarbonate, or chloride type. TDS and chloride concentrations increase from west to east. Large sulfate concentrations are limited to areas underlain by Pennsylvania shale, sandstone, and siltstone (Kleeschulte and Emmett, 1986).

The water quality of the deep bedrock aquifer varies with depth and lateral extent. Samples from the confining portion of the aquifer (the Maquoketa-Joachim sequence) have TDS values ranging from 305 to more than 4,700 mg/l. Water in the north and northeast portions of St. Charles County has high TDS and is a sodium chloride type, while water to the west is generally a calcium magnesium bicarbonate type. Water samples from the more permeable portion of the deep bedrock aquifer (the St. Peter-Gasconade sequence) had a TDS ranging from 252 to 915 mg/l. The eastern half of the county yields highly mineralized sodium chloride type water, while the western half yields moderately mineralized calcium magnesium bicarbonate type water (Kleeschulte and Emmett, 1986).

The dissolution potential of the bedrock underlying the site is variable as evidenced by the differences in solution features of the various bedrock units.

1.2.8 Contaminant Sources

Past operations and waste handling practices at the WSS have resulted in several potential sources for contamination of surface water, groundwater, and soil.

Fishel and Williams (1944) provided one of the first records of contamination sources. Their report stated that there were seven lagoons receiving wastewater from the Army's operation. At various times, wastewater was discharged directly into surface streams. There were also a number of catchment tanks receiving wastewater from the production lines. These would apparently overflow into small gullies flowing into nearby streams.

Also, red water leaking from a waste storage lagoon located 100 yards east of Frog Pond reportedly re-surfaced at springs SP6303 and SP6501, known as the Francis Howell Cemetery Wet Weather Spring and the 500-foot contour spring, respectively (Fishel and Williams, 1944; Hoffman, 1988).

Ryckman, Edgerly, Tomlinson, and Associates (RETA, 1978) indicated that wastewaters containing sulfate derivatives from DOA operations are known to have contaminated Schote and Dardenne creeks. They further indicated that explosives production resulted in chemical contamination of structures, concrete foundations, soil, underground transport lines, and catch basins. Some of the processing equipment, buildings, appurtenances, and contaminated soil were removed prior to AEC construction activities at the site. During the AEC's operation, radiological contamination of five major process buildings, most of the support buildings, and terrain behind the plant resulted from equipment being operated beyond design capacity, limitations of raffinate disposal facilities, and poor onsite "housekeeping" activities. During the decontamination operation in 1968 for conversion of part of the facility (Buildings 103 and 105) to herbicide ("Agent Orange") production, barrels of concrete and debris were left near Raffinate Pit 4 and in the Ash Pond area. These barrels have rusted, are partially deteriorated and have spilled their contents on the ground (RETA, 1978).

MKF (1987b) reported some additional contaminant sources during their Water Quality Phase I Assessment Report (1987b). Nitroaromatics and residues were burned during decontamination efforts by the Army in 1946. MKF (1987b) described potential nitroaromatic source areas associated with the Ordnance Works which are shown in Figures 1-24 and 1-25. A former surface impoundment northwest of the Missouri Highway Department was used

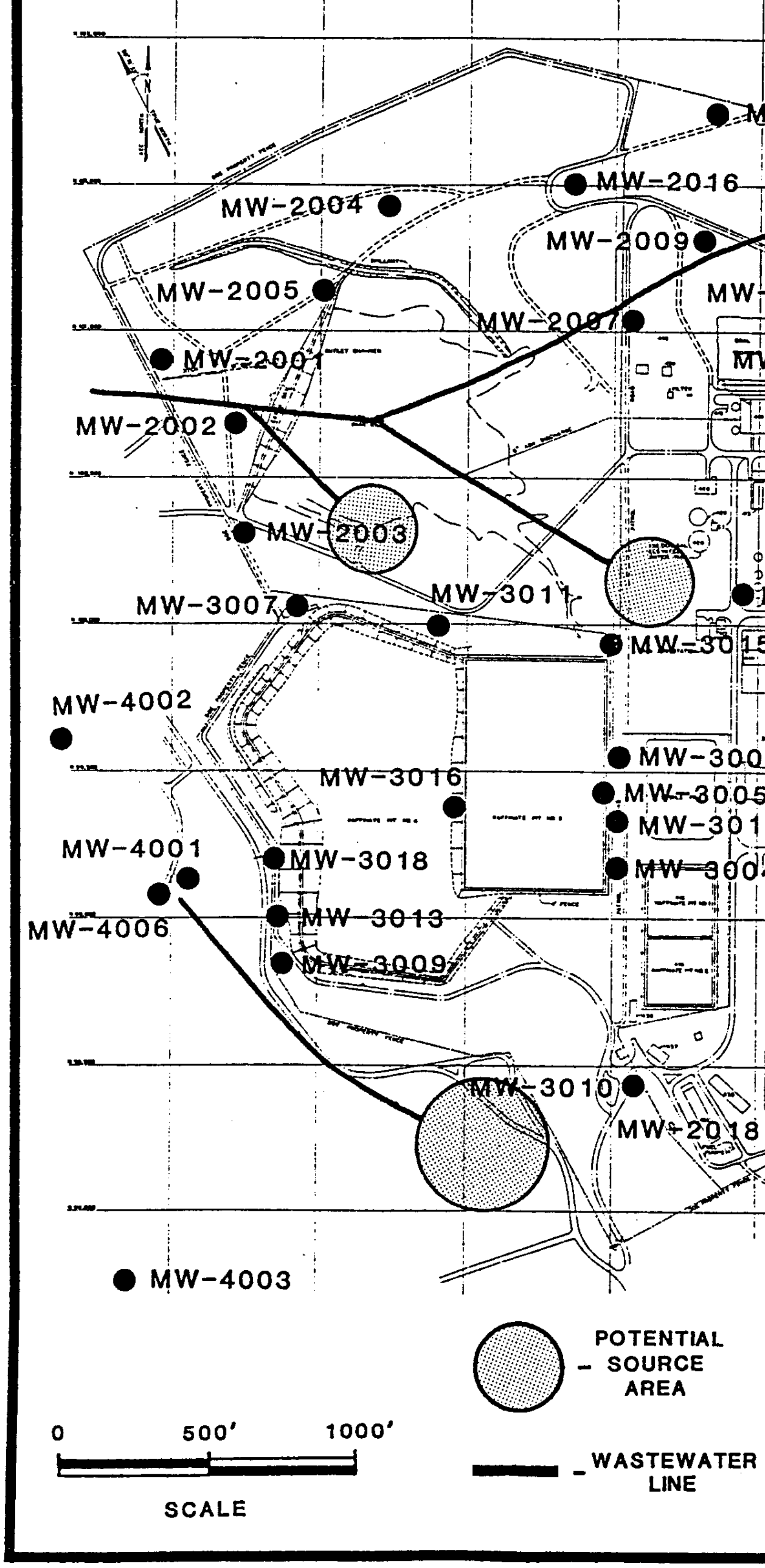


FIGURE 1-24

POTENTIAL NITROAROMATIC SOURCE AREAS AND MONITORING WELLS AT THE WSCP/WSRP

SOURCE: MK-FERGUSON 1987

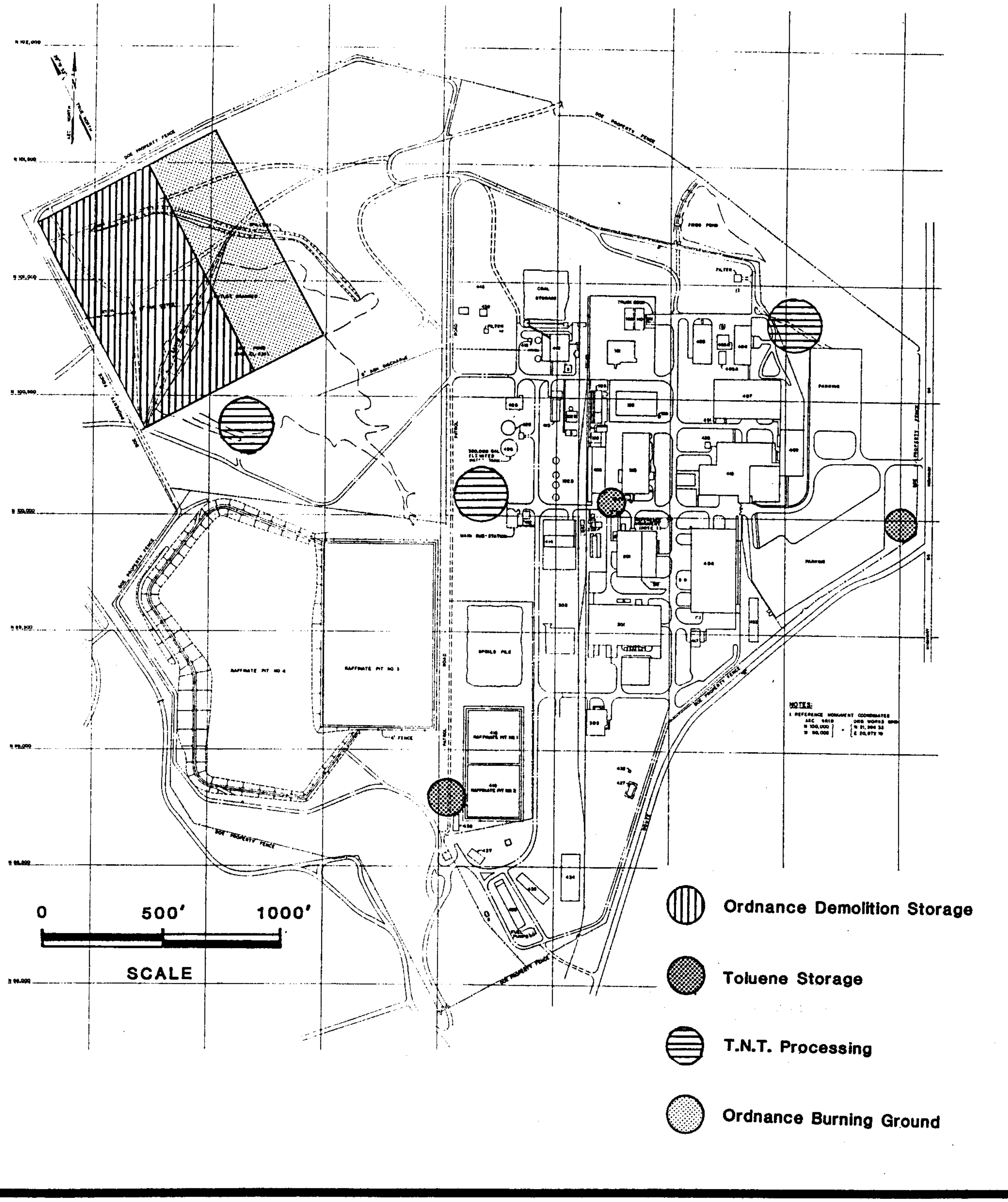


FIGURE 1-25

POTENTIAL CHEMICAL CONTAMINATION SOURCE AREAS ASSOCIATED WITH THE FORMER WELDON SPRING ORDNANCE WORKS as a wastewater retention basin for the Weldon Spring Ordnance Works.

MKF (1987b) has also identified potential source areas for specific contaminants associated with radioactive materials processing. These are listed in Table 1-9 and illustrated in Figure 1-26. MKF also analyzed water quality in the raffinate pits. These results are shown in Tables 1-10 and 1-11. These data confirm that Pits 1 and 3 are potential nitrate sources while Pits 2 and 3 are potential sources of sulfate.

1.2.9 Potential Migration Pathways

The previous subsection has discussed potential contaminant sources. Whenever sufficient quantities of the contaminant are present, migration of some of the contaminant is likely. There are three general pathways that may be applicable at any site: air, surface, and subsurface.

Air migration pathways exist for the WSS and historically have played a role in transport of some contaminants, but documentation is limited. RETA (1978) reported that the air pathway is not a major route because there is no longer any active source of materials available for air transport. During the 1959-1965 period, environmental air sampling in the vicinity of the site indicated that the levels of uranium detected were typically less than 10% of the maximum permissible concentration (Mallinckrodt, 1959-1965).

Surface water probably was and is an important pathway for movement of contaminants from the site. The potential for distant migration of contamination via overland flow is minimal because of the generally gentle slopes. Migration via channelized flow over appreciable distances, however, is much more likely. A surface channel remnant exists through the Ash Pond area. There are also numerous relatively small drainage

TABLE 1-9

POTENTIAL GROUNDWATER CONTAMINATION SOURCE AREAS ASSOCIATED WITH THE WELDON SPRING SITE (MKF, 1987b)

Potential Source Areas	Contaminant
Nitric Acid Recovery Plant (Area 100)	Nitrates
Digestion & Denitration Plant (Bldg. 103)	
Refinery Tank Farm (Area 102)	
Spills from above areas	
Process line & sewer leaks	
Past management practices	
Raffinate Pits sludge	
HNO3 used in production of TNT/DNT	
Spills & poor waste management practices during the World War II production effort	
Raffinate Pits sludge which contains sulphur	Sulfates
Green Salt Plant (Bldg. 201);	Fluoride
Green Salt Farm (Area 202);	
Metal Pilot Plant (Bldg. 404);	
Raffinate Pits sludge	
	Metals
Metals Plant (Bldg. 301)	Magnesium
Magnesium Bldg. (Bldg. 302)	
Metal Pilot Plant (Bldg. 404)	Lithium
Raffinate Pits Water	Chromium
Raffinate Pits Water	Nickel
Raffinate Pits Water	Vanadium

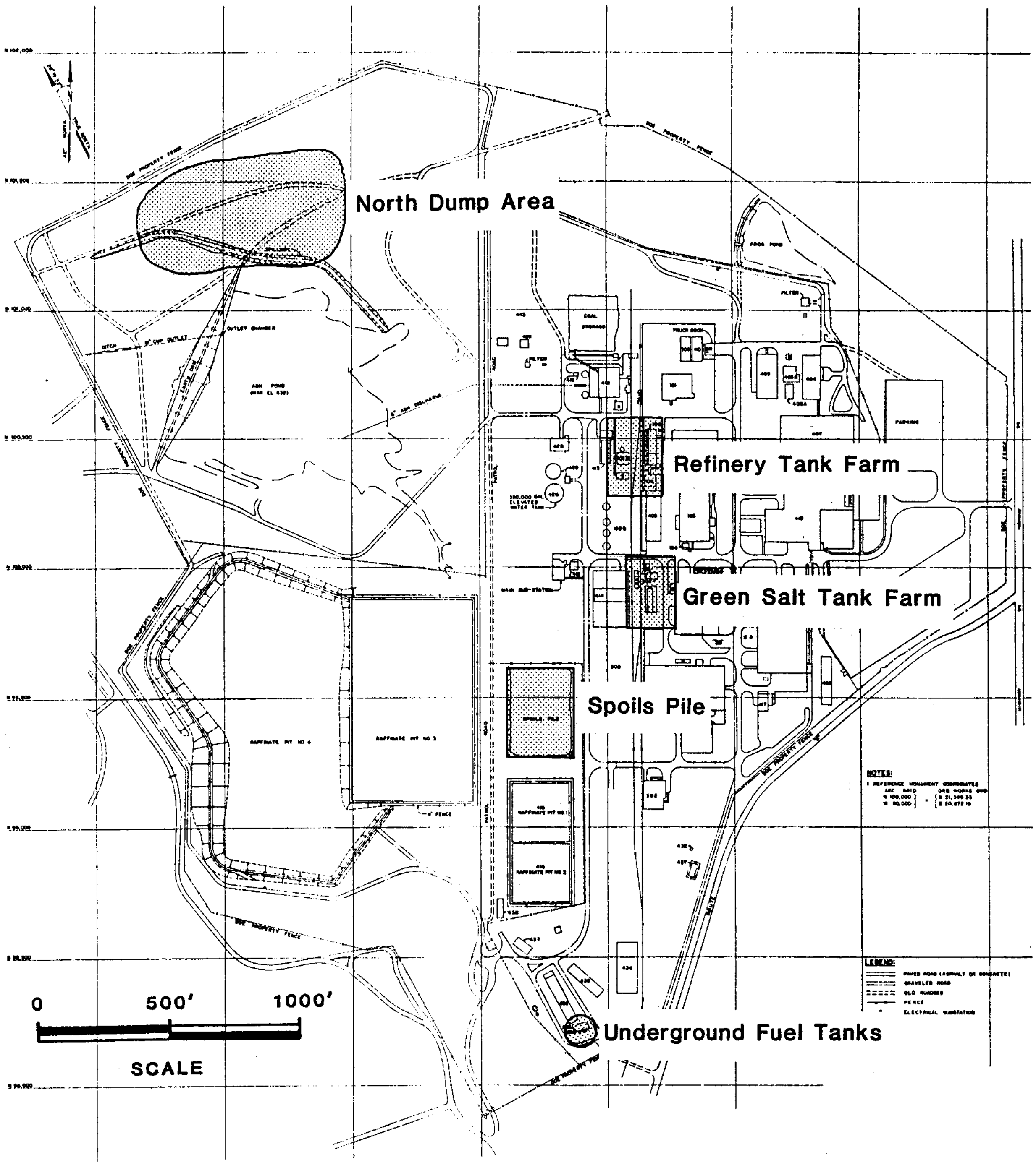


FIGURE 1-26

POTENTIAL CHEMICAL CONTAMINATION SOURCE AREAS ASSOCIATED WITH THE WSCP/WSRP

TABLE 1-10

INORGANIC ANION AND WATER QUALITY DATA FOR THE RAFFINATE PITS

	Concentration (mg/L)								
U.S. E.P.A. Primary/Secondary Drinking Water Standard	Nitrate (as N)	Sulfate	Chloride	Fluoride	Hardness	TDS	TOC	Cyanide CWA* Standard	Phenol
	10	250	250	2	500	S	S	0.2	3.5
Raffinate Pit 1 (SW-3001) 4/24/87	422	231	1.50	1.90	872	3160	12	0.032	<0.005
Raffinate Pit 2 (SW-3002) 4/24/87	10.1	493	2.34	1.57	422	818	8	0.025	<0.005
Raffinate Pit 3 (SW-3003) 4/24/87	947	704	3.37	4.84	2107	6390	6	0.027	<0.005
Raffinate Pit 4 (SW-3004) 4/24/87	46.6	136	5.69	4.69	252	694	8	0.032	<0.005

S - No Drinking Water Standard *CWA - Clean Water Act Source: WSSRAP, 1987

TABLE 1-11
CLP METALS CONCENTRATIONS IN THE RAFFINATE PITS (4/24/87)

Concentration (ug/L)

	Al	Sb	Ar	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Hg	Ni	K	Se	Ag	Na	Tl	V	Zn
U.S. E.P.A. Primary/Scndry Drinking Water Standard (ug/L)	--	--	50	1000	--	10	--	50	--	1000	300	50	--	--	50	2	--	--	10	50	--	--	S	5000
*CRDL - (ug/L)	200	60	10	200	5	5	5000	10	50	25	100	5	--	5000	15	0.2	40	5000	5	10	5000	10	50	20
Location No.																								
Raffinate Pit # 1 (SW-3001)	405	U	22	71	8	0.5	254000	85	U	45	109	22	U	15400	17	U	11	28400	U	25	388000	U	2090	9
Raffinate Pit # 2 (SW-3002)	279	102	38	31	7	U	105700	83	U	12	220	U	U	40800	14	U	48	14300	U	10	113000	U	1800	15
Raffinate Pit # 3 (SW-3003)	517	395	5	86	3	U	260500	194	33	30	433	257	U	196000	33	U	174	78200	U	40	900000	U	535	26
Raffinate Pit # 4 (SW-3004)	230	U	U	102	U	U	11600	31	U	19	101	358	U	39400	10	U	33	15200	U	8	172000	U	89	19

Source WSSRAP, 1987

* - Contract Required Detection Limits, US EPA Contract Laboratory Program
U - Undetected at Contract Required Detection Limits

channels that would tend to spread contaminants from their place of origin. Some of these drainage channels include pipelines for portions of their alignment. Section 1.2.3 briefly discussed other surface drainage features that could permit the migration of contaminants. These include the spillway for Ash Pond and the channels draining to the Southeast Drainage Easement, and channels draining to Frog Pond.

Potential subsurface migration pathways at WSS include: buried sewer and process pipelines, particularly those that have deteriorated; natural subsurface features such as relatively impervious layers that tend to impede the downward movement of water and therefore result in lateral spreading; permeable pathways that are relatively isolated but continuous laterally or vertically, such as solution channels, caverns, or joint-sets; and permeable media of a relatively continuous nature, such as permeable limestone with a combination of fractures, joints, and solution enlarged features. All of these subsurface pathways exist at the site, to some degree.

1.2.10 Contaminant Levels/Migration

Fishel and Williams (1944) presented historical accounts of observed contamination of surface and groundwater by TNT manufacturing wastes in the vicinity of the WSS. Later measurements of water quality parameters indicate contamination of the surface water and groundwater at the site and immediate vicinity. Numerous environmental monitoring reports have been produced over the years by Mallinckrodt Chemical Works (1959-1965), DOA (1977-1985), BNI (1983-1986), National Lead Company of Ohio (1981-1982), Shell Engineering (1983-1985), and MKF (1986). Other historical data are summarized in the Draft Environmental Impact Statement for remedial action at the site (DOE, 1987).

Kleeschulte and Emmett (1986) and Kleeschulte, et al (1986) present 1984 and 1986 water quality data for the site and vicinity for groundwater and surface water. These analyses were for a limited set of parameters. Analytical results indicate elevated levels of calcium, magnesium, sodium, sulfate, nitrate, lithium, strontium, and uranium for wells near the raffinate pits with nitrate (as N) concentrations of 53 to 990 mg/l. Uranium concentrations for wells near the raffinate pits ranged from 6 to 86 ug/l. Surface water sample results showed elevated levels of TDS, nitrate, and uranium for the raffinate pits, Frog Pond tributary, and Burgermeister Spring (a spring located approximately 7000 ft north of Raffinate Pit 4).

Figure 1-27 illustrates the locations of existing monitoring wells. Well numbers, location coordinates (based on original AEC plant grid), depths, and other information are presented on Table 1-12. The 28 monitoring wells described include only those wells that are suitable for water level measurements and groundwater sampling; wells that are dry, damaged, or destroyed are excluded. Twenty-one wells are located in the raffinate pits and chemical plant area. Four wells are located outside the site boundaries in the Weldon Spring Training Area (WSTA) which is owned by the U.S. Department of the Army, and one well is located in the Weldon Spring Wildlife Area which is administered by the Missouri Department of Conservation. Monitoring wells with a 2000 series number are located within the chemical plant area; wells with a 3000 series number are located in the raffinate pits area, and wells with a 4000 series number are located outside of the site boundaries.

The wells were installed in 1983 and 1986 during hydrogeological studies by Bechtel National, Inc. (BNI). Six wells - MW-2020, MW-4002, MW-4003, MW-3007, MW-3008, MW-3009, and MW-3010 - penetrate from 21 to 76 feet of the saturated thickness of the Burlington-Keokuk aquifer. These six were constructed with 4-inch diameter PVC casing through the unconsolidated soil and an uncased open borehole in the bedrock. Although groundwater

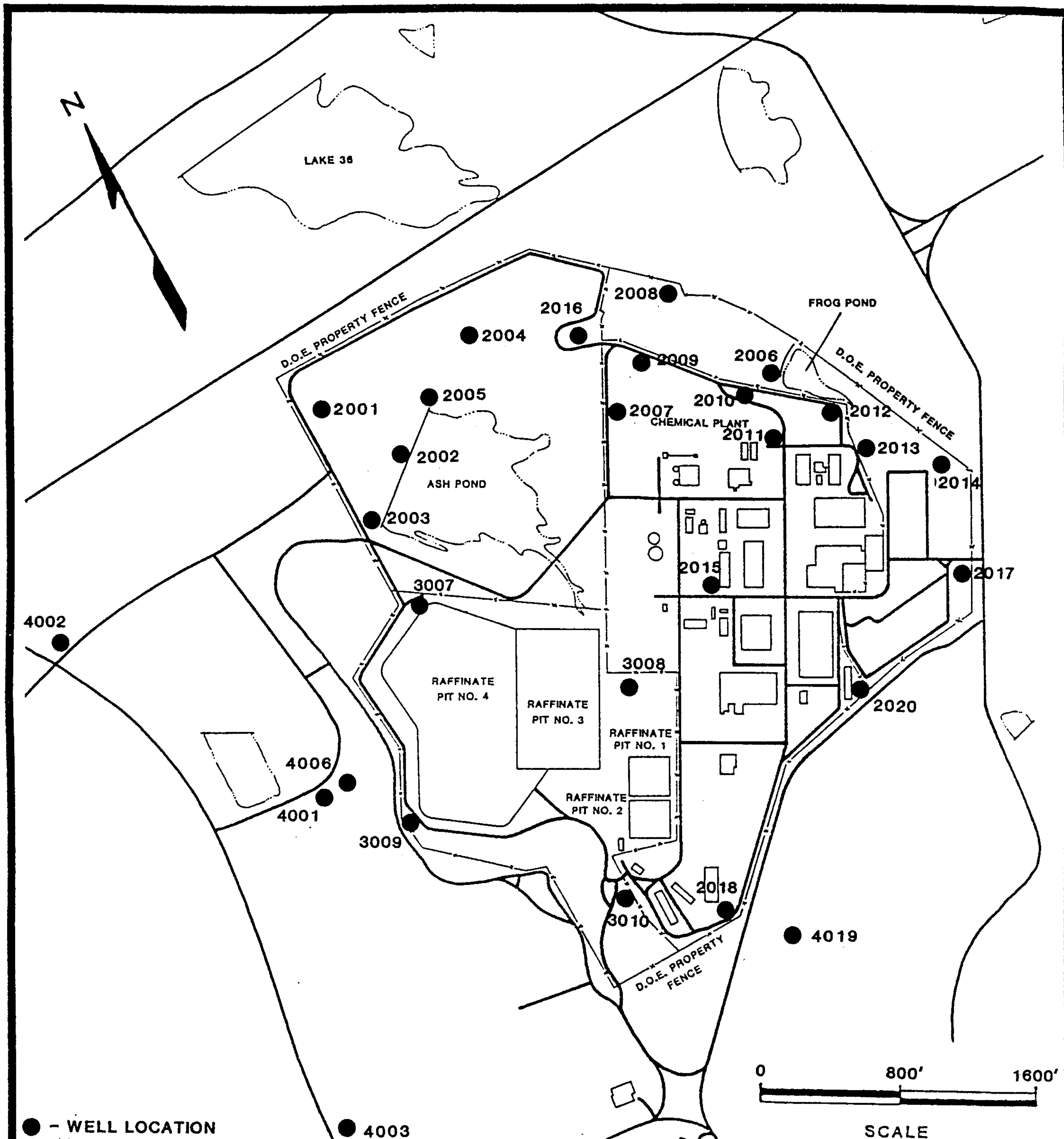


FIGURE 1-27

EXISTING MONITORING WELLS

TABLE 1-12

GROUNDWATER MONITORING WELL DATA SHEET

WSCP/WSRP AND VICINITY

WELL NUMBER	OLD WELL NUMBER	APPROXIMATE LOCATION COORDINATES NORTH	WEST	TOTAL WELL DEPTH FT. BTOC	APPROX. ELEV. OF GROUND SURFACE NGVD	ELEV. OF TOP OF CASING NGVD	BOTTOM WELL ELEV. FT. NGVD	SCREEN LENGTH FT.	BOTTOM OF FILTER PACK ELEVATION NGVD	LENGTH OF FILTER PACK	BOREHOLE DIAMETER IN.	CASING DIAMETER IN.	CLUSTERED WELL NUMBER	DEPTH TO STATIC WATER LEVEL FT. BTOC	STATIC WATER LEVEL ELEV.	APPROX. ELEV. OF TOP BEDROCK NGVD	APPROX. SATURATED THICKNESS PENETRATED BY WELL FT.
MW 2001	GMW-1	100858	52554	61.0	612	613.45	552.5	10	547.5	32.5	8.5	2		25.42	588.03	586.0	36
MW 2002	GMW-2	100658	52253	61.0	626	625.65	564.7	10	559.7	32.3	8.5	2	MW 2020	32.60	593.05	595.0	28
MW 2003	GMW-3	100347	52299	61.0	637	638.74	577.7	10	552.7	22.5	8.5	2		40.96	597.78	598.0	20
MW 2004	GMW-4	101450	51750	78.5	642	644.73	566.2	10	565.7	22.7	8.5	2	MW 2029	61.04	583.69	592.0	17
MW 2005	GMW-5	101131	51950	78.5	635	637.45	559.0	10	554.5	31.0	8.5	2	MW 2022	49.90	587.55	591.0	29
MW 2006	GMW-6	101223	49852	68.5	634	636.00	567.5	10	563.0	44.0	8.5	2	MW 2026	36.42	599.58	611.0	32
MW 2007	GMW-7	100928	50933	96.0	652	653.70	557.7	10	552.7	36.7	8.5	2		60.81	592.89	590.0	35
MW 2008	GMW-8	101720	50659	58.5	623	624.73	566.2	10	562.7	29.0	8.5	2	MW 2025	36.19	588.54	588.0	22
MW 2009	GMW-9	101350	50700	61.0	637	638.71	577.7	10	577.7	31.4	8.5	2		41.32	597.39	616.0	20
MW 2010	GMW-10	101150	50100	61.0	642	644.75	583.8	10	578.8	26.8	8.5	2		44.79	599.96	609.0	16
MW 2011	GMW-11	100916	50030	76.0	653	655.37	579.4	10	574.2	42.4	8.5	2		54.58	600.79	621.0	21
MW 2012	GMW-12	101050	49643	61.0	636	637.70	575.7	10	565.2	40.2	8.5	2		32.32	604.38	611.0	29
MW 2013	GMW-13	100819	49539	70.9	645	647.12	576.2	10	570.2	43.7	8.5	2	MW 2027	42.88	604.24	618.0	37
MW 2014	GMW-14	100735	49186	61.0	647	649.33	588.3	10	583.3	27.0	8.5	2		45.40	603.93	614.0	16
MW 2015	GMW-15	100100	50550	81.0	657	659.90	578.9	10	571.4	38.7	8.5	2	MW 2028	56.28	603.62	612.0	25
MW 2016(2)		101532	51176	152.4	635	636.89	484.5	GROUTED						57.88	579.01	585.0	--
MW 2017	GMW-17	100200	49050	66.1	658	659.84	593.7	10	588.7	39.0	8.5	2		54.62	605.22	634.0	12
MW 2018	GMW-18	98297	50382	66.1	665	663.44	597.3	10	592.3	31.6	8.5	2	MW 2019	48.51	614.93	629.0	18
MW 2019		98287	50391	117.2	662	663.17	546.0	10	545.7	13.3	8.5	4	MW 2018	71.49	591.68	618.0	44
MW 2020	B-4	99548	49549	121.4	655	656.88	535.5	--		--	3.0	OPEN		47.47(1)	609.41(1)	637.0	74
MW 2021		100635	52263	112.2	624	626.07	513.9	10	513.6	14.75	8.5	4	MW 2002	37.39	588.68	602.0	74
MW 2022		101154	51946	127.1	636	637.28	510.2	10	510.1	14.0	8.5	4	MW 2005	51.67	585.61	591.2	76
MW 2023		101551	51141	92.2	636	637.38	544.6	20	543.6	23.0	8.5	2	MW 2024	53.88	582.91	583.0	21
MW 2024		101552	51186	151.4	635	636.79	485.4	10	485.4	12	8.5	4	MW 2023	69.12	568.26	583.0	96

TABLE 1-12 (Cont'd)

GROUNDWATER MONITORING WELL DATA SHEET

WSCP/WSRP AND VICINITY

WELL NUMBER	OLD WELL NUMBER	APPROXIMATE LOCATION COORDINATES NORTH	WEST	TOTAL WELL DEPTH FT. BTOC	APPROX. ELEV. OF GROUND SURFACE NGVD	ELEV. OF TOP OF CASING NGVD	BOTTOM WELL ELEV. FT. NGVD	SCREEN LENGTH FT.	BOTTOM OF FILTER PACK ELEVATION NGVD	LENGTH OF FILTER PACK	BOREHOLE DIAMETER IN.	CASING DIAMETER IN.	CLUSTERED WELL NUMBER	DEPTH TO STATIC WATER LEVEL FT. BTOC	STATIC WATER LEVEL ELEV.	APPROX. ELEV. OF TOP BEDROCK NGVD	APPROX. SATURATED THICKNESS PENETRATED BY WELL FT.
MW 2025		101688	50649	108.6	622	624.05	515.5	10	515.3	13.0	8.5	4	MW 2008	40.24	583.81	593.0	68
MW 2026		101215	49861	120.3	631	633.44	513.1	10	513.0	12.5	8.5	4	MW 2006	46.04	587.40	611.4	72
MW 2027		100858	49546	121.8	646	646.83	525.0	10	524.6	15.0	8.5	4	MW 2013	52.51	594.32	619.0	68
MW 2028		100092	50543	132.8	658	659.65	526.8	10	526.3	15.5	8.5	4	MW 2015	64.17	595.48	613.5	67
MW 2029		101453	51734	103.1	643	645.24	542.1	10	542.1	12.5	8.5			62.69	582.55	592.0	38
MW 3001		99100	51250	77.2	664	664.20	589.2	20	586.2	25.3	8.5	2	MW 3002	53.94	610.26	610.0	23
MW 3002		99100	51240	147.5	664	664.00	519.2	10		13.5	8.5	4	MW 3001			611.0	--
MW 3003		100046	52094	90.8	644	645.91	555.1	10	554.8	13.8	8.5	2	MW 3006	48.14	597.77	617.0	43
MW 3006		100049	52071	136.2	646	647.05	511.2	10	510.7	15.5	8.5	4	MW 3003	56.96	590.09	614.0	79
MW 3007(2)	B-17	100043	52683	99.9	645	647.72	547.8	GROUTED						45.55	602.17	621.0	--
MW 3008	B-19A	99546	50954	104.0	645	646.43	542.4	--		--	3.0	OPEN		36.06	609.97	617.0	68
MW 3009	B-21	98832	52123	101.5	645	646.43	544.9	--		--	3.0	OPEN		37.92	608.51	615.0	64
MW 3010	B-23	98471	50936	92.6	665	666.94	574.3	--		--	3.0	OPEN		58.79	608.15	627.0	34
MW 3019		97933	50946	85.5	660	661.94	576.4	10	576.4	13.7	8.0	2		56.21	605.73	633.0	28
MW 4001	GMW-16	99049	52567	41.8	661	622.74	580.9	10		13.6	8.5	2	MW 4007	20.66	602.08	610.0	22
MW 4002	B-9	99848	54284	87.4	634	635.32	547.9	--		--	3.0	OPEN		66.32	569.00	612.0	21
MW 4003	B-11	96958	52459	108.1	670	671.67	563.6	--		--	3.0	OPEN		58.79	612.88	653.0	49
MW 4004		97749	51689	76.4	652	653.06	576.7	10	576.7	12.0	8.0	2		41.26	611.80	630.0	34
MW 4005		97710	52372	79.3	657	657.25	577.9	10	577.7	14.7	8.5	2		47.74	609.51	627.0	31
MW 4006(3)	B-16	99084	52513	29.8	620	622.96	593.2	5		8.0	6.0	2		20.39	602.57	603.0	9
MW 4007		99069	52545	92.2	623	624.06	531.9	10	531.5	13.0	8.5	4	MW 4001	28.27	595.79	610.0	62
MW 4008		98669	53180	84.6	637	637.26	552.7	10	552.5	13.0	8.5	2		40.12	597.14	605.0	43
MW 4009		99517	52672	78.2	624	625.82	547.6	10	547.4	12.8	8.5	2		31.68	594.14	607.0	45
MW 4010		100103	53030	78.5	629	630.68	552.2	10	552.0	10.2	8.5	2		41.58	589.10	614.3	35

TABLE 1-12 (Cont'd)

GROUNDWATER MONITORING WELL DATA SHEET

WSCP/WSRP AND VICINITY

WELL NUMBER	OLD WELL NUMBER	APPROXIMATE LOCATION COORDINATES NORTH	WEST	TOTAL WELL DEPTH FT. BTOC	APPROX. ELEV. OF GROUND SURFACE NGVD	ELEV. OF TOP OF CASING NGVD	BOTTOM WELL ELEV. FT. NGVD	SCREEN LENGTH FT.	BOTTOM OF FILTER PACK ELEVATION NGVD	LENGTH OF FILTER PACK	BOREHOLE DIAMETER IN.	CASING DIAMETER IN.	CLUSTERED WELL NUMBER	DEPTH TO STATIC WATER LEVEL FT. BTOC	STATIC WATER LEVEL ELEV.	APPROX. ELEV. OF TOP BEDROCK NGVD	APPROX. SATURATED THICKNESS PENETRATED BY WELL FT.
MW 4011		100550	52780	77.0	626	627.20	551.1	10	549.2	14.6	8.5	2		38.10	589.10	596.0	38
MW 4012		101642	53034	77.2	615	617.32	540.1	10	539.9	12.8	8.5	2		46.83	570.49	584.0	29
MW 4013		101916	52193	61.3	607	608.65	547.3	20	547.3	22.0	8.5	2		48.14	560.51	574.0	12
MW 4014		102267	51592	66.6	608	609.10	542.5	20	542.5	22.0	8.5	2		47.73	561.37	567.0	17
MW 4015		102150	50509	64.7	618	619.58	554.9	20	554.7	23.2	8.5	2		38.17	581.41	607.0	27
MW 4016		102003	49982	84.6	643	644.03	559.2	10	559.2	12.3	8.5	2		54.32	589.71	614.0	29
MW 4017		101612	49287	85.0	649	649.97	565.0	20	565.0	22.2	8.5	2		56.66	593.31	601.0	28
MW 4018		101233	48677	76.4	648	649.93	573.5	10	568.5	18.0	8.5	2		52.23	597.70	606.0	22
MW 4019	GMW-19	98063	50161	61.0	645	647.17	586.2	10		19.0	8.5	2		35.58	611.59	623.0	26
MW 4020		99933	48704	78.3	658	659.16	580.9	10	580.7	12.0	8.5	2		54.06	605.10	623.0	23
MW 4021		99170	49188	72.8	650	651.86	579.1	20	579.1	22.0	8.5	2		44.11	607.75	625.0	26
MW 4022		97460	50447	90.4	666	667.91	577.5	20	577.3	20.0	8.5	2		71.17	596.74	633.0	19
MW 4023		98718	49845	55.0	646	648.48	593.5	20	592.5	22.5	8.5	2		33.71	614.77	620.0	31

NOTES: Static Water Levels measured 07/23/88 except as noted.

(1) Measured 06/07/88
(2) Measured 04/30/87
(3) Overburden Monitoring Well included in bedrock water level monitoring program.
(4) Wells MW 2001 through MW 2018 have one foot of blank casing below screen. Other wells are capped at base of screen.

Tabulated data are preliminary - based on partially validated data. New well designations established October 1986.

samples and water level measurements can be collected from these wells, they are not representative of discrete zones within the aquifer. It is not possible to determine vertical flow patterns or vertical distribution of contaminants from these wells.

Monitoring well MW-4006 was installed to a depth of 28.5 feet below ground surface. This well was constructed with a 2-inch PVC casing and has 0.040-inch opening factory slotted screens.

Nineteen wells (MW-2001 through MW-2015, MW-2017, MW-2018, MW-4019, and MW-4001) are screened in the upper, weathered portion of the Burlington/Keokuk Formation, penetrating from 12 to 37 feet of saturated thickness.

BNI sampled groundwater and raffinate pits water in September and October 1986 for chemical and radiological analyses. These data suggest leakage from the pits: groundwater analyses for wells upgrade of the raffinate pits are significantly different from sample analyses from the pits, while analyses from wells downgrade of the pits are of similar water quality (BNI, 1987). None of the previously mentioned data and reports contain sufficient information regarding sample collection, preservation and analytical methodologies to allow the presented data to be validated according to the data validation procedures in the QAPP. However, these data are useful as background information.

MKF presents the first comprehensive water quality assessment for groundwater and surface water systems at WSS and vicinity in the Phase I Water Quality Assessment (1987b). This assessment consisted of sampling 50 monitoring wells and 23 surface water locations. Groundwater samples were analyzed for the complete hazardous substance list, nitroaromatics, selected inorganic anions, water quality indicators, and radionuclides. Surface water samples were analyzed for radionuclides, selected inorganic anions, water quality indicators, and metals as listed on the EPA Contract Laboratory Program (CLP) list.

Conclusions from the Assessment (MKF, 1987b) include:

- Raffinate Pit 3 appears to be contributing nitrate and dissolved metals to the groundwater.

- Raffinate Pit 4 appears to be contributing sulfate to the groundwater.

- Nitroaromatics are present in groundwater at high concentrations (400 ppb total) under the northeast corner of the WSS.

- General low-level nitroaromatic contamination exists over most of the WSS.

- Three lakes on the Busch Wildlife Area receive radiological contamination from the site.

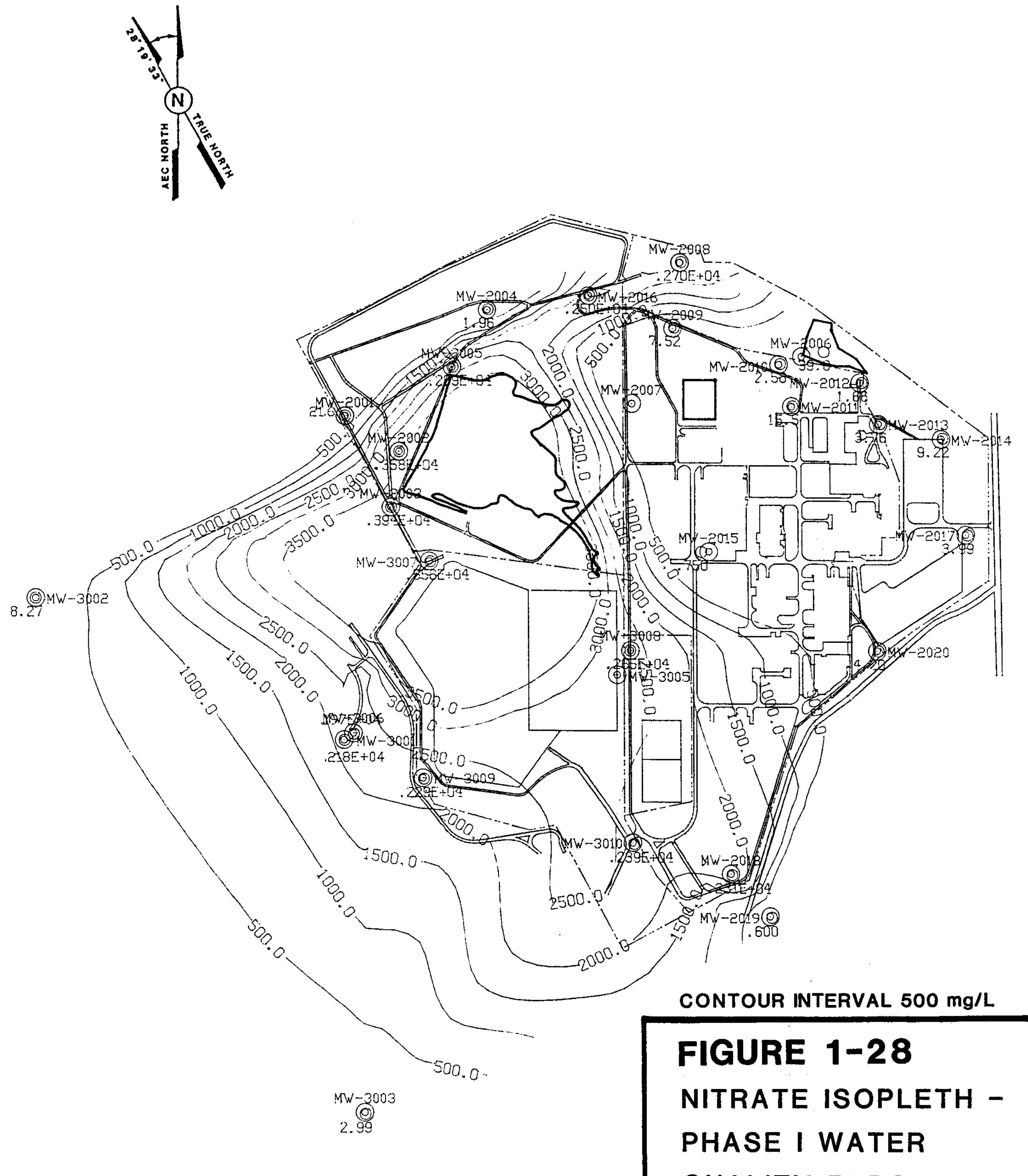
Nitrate concentrations in monitoring wells are shown in Table 1-13. Sample numbers correspond with monitoring well numbers. Nitrate isopleths are presented in Figure 1-28.

The apparent contamination source for the nitrate is Raffinate Pit 3. This conclusion was drawn by correlating metals (antimony, chromium, magnesium, and vanadium) and nitrate concentrations in Raffinate Pit 3 water and sludge with concentrations in monitoring wells. Concentrations of nitrate in the plume do not decrease gradually as would be expected, but decline rapidly between the northern edge of the raffinate pits and the northern site boundary. It is possible that this decline is due to a hydrogeologic discontinuity such as a series of solution-enlarged joints or fractures which intercept the plume. Elevated sulfate concentrations were detected in the western portion of the site, centered under Raffinate Pit 4 (see Table 1-13). Sulfate contamination may occur from water percolating through raffinate pit sludges, known to contain high

Table 1-13
INORGANIC ANION DATA FOR GROUNDWATER AT THE WSCP/WSRP

		Concentration mg/L								
U.S. E.P.A. Primary/Secondary Drinking Water Standard	mg/L	Nitrate (as N) 10	Sulfate 250	Chloride 250	Fluoride 2	TDS 500	TOC S	Hardness S	Cyanide CWA* 0.2	Phenol Standard 3.5
Sample No.	Date Sampled									
GW-2001	3/3/87	4.8	22.5	5.12	<0.25	362	<1	307	U	U
GW-2002	3/4/87	806	198	23.2	14.9	1360	1	664	U	U
GW-2003	3/4/87	886	223	33.2	14.7	2724	16	985	U	U
GW-2003-D	3/4/87	945	232	32.8	14.6	2520	<1	1331	U	U
GW-2004	3/3/87	0.4	6.26	1.14	<0.25	374	63	305	U	U
GW-2005	3/5/87	605	172	4.43	1.01	1562	2.12	419	U	U
GW-2006	3/2/87	8.8	31.4	87.1	<0.25	570	7	411	U	0.016
GW-2007	3/2/87	<0.1	17.9	1.34	<0.25	320	<1	312	U	U
GW-2008	3/4/87	608	166	64.2	17.0	622	1	375	U	0.013
GW-2009	3/3/87	1.7	38.2	8.04	<0.25	596	2	448	U	U
GW-2010	3/3/87	0.6	56.8	32.2	<0.25	590	2	374	U	U
GW-2011	3/3/87	3.5	11.3	4.44	<0.25	314	1	279	U	U
GW-2012	3/3/87	0.4	74.2	32.2	<0.25	546	57	352	U	U
GW-2013	3/2/87	0.9	26.9	8.62	0.40	688	6	415	U	U
GW-2014	3/2/87	2.2	34.5	2.83	0.28	570	3	460	U	U
GW-2015	3/6/87	0.2	158	2.46	<0.25	570	3.26	502	U	0.011
GW-2015-D	3/6/87	<0.1	158	2.12	0.25	568	2.96	514	U	U
GW-2016	3/4/87	562	112	18.1	15.3	656	2	328	U	U
GW-2017	3/2/87	0.9	462	10.8	0.62	1000	1	735	U	U
GW-2018	3/5/87	519	18.8	2.45	0.54	642	0.98	352	U	U
GW-2020	3/6/87	0.9	241	38.4	<0.25	680	8.21	434	U	U
GW-3007	3/4/87	1251	866	52.2	12.4	5260	10	2594	U	U
GW-3008	3/10/87	597	100	31.7	1.51	6028	2.06	3482	U	0.014
GW-3009	3/5/87	515	34.2	1.64	0.58	728	2.20	478	U	0.020
GW-3010	3/5/87	296	23.8	2.21	0.38	500	1.85	322	U	U
GW-3010-D	3/5/87	537	23.0	2.34	0.55	506	1.55	333	U	U
GW-3013	3/5/87	468	915	2.30	1.09	1436	3.51	997	U	U
GW-4001	3/5/87	491	159	1.48	0.55	652	14.1	367	0.018	0.011
GW-4002	3/6/87	1.9	25.0	2.16	<0.25	232	24.8	219	U	U
GW-4003	3/6/87	0.7	36.0	7.40	<0.25	308	8.78	294	U	U
GW-4006	3/5/87	444	129	0.78	0.44	402	17.7	226	U	0.011
GW-4019	3/6/87	0.1	9.01	0.91	<0.25	278	3.77	280	U	0.026

S = No Drinking Water Standard
D = Duplicate Sample
*CWA = Clean Water Act
Source: WSSRAP, 1987



CONTOUR INTERVAL 500 mg/L

FIGURE 1-28

NITRATE ISOPLETH - PHASE I WATER QUALITY REPORT

NOTE : NITRATE SHOWN AS NO3

SOURCE : MK-FERGUSON-1987

concentrations of sulfur. Computer-generated sulfate isopleths are presented in Figure 1-29. Sulfate concentrations gradually decrease with distance from the source, also suggesting a different source from the nitrate contamination.

Figures 1-28 and 1-29 depict nitrate and sulfate contamination. These isopleths are computer generated, based on limited data, and shape configuration is governed by reading monitor wells in existence in March 1987. Other factors that may modify configuration include rock fracture orientation, gradient, the existence of perched groundwater zones, and the chemical, physical and biological processes in the vadose zone and aquifer. They present only a general representation of extent of contamination.

Nitroaromatics were detected at low ug/L concentrations in most monitoring wells sampled during the Phase I Assessment (see Table 1-14). Nitroaromatics were also observed at high concentrations in the northeast portion of the WSCP. The highest concentrations were present near the final production area of TNT Line No. 1, which is a potential source area. Another potential source is the former site of the Weldon Spring Ordnance Works wastewater lagoon, located just north of the site boundary and immediately west of the Missouri Highway Department's maintenance facility. Soil sampling performed in 1987 indicated nitroaromatic concentrations as high as 1% by weight in soil samples from the old waste lagoon.

Surface water sampling at and near the WSCP/WSRP confirmed earlier monitoring results which concluded that Busch Wildlife Area Lakes 34, 35, and 36 receive direct or indirect uranium-contaminated runoff from the WSCP/WSRP. No significant chemical contamination attributable to the WSCP/WSRP was observed in any surface water. Slightly elevated nitrate levels were observed in Burgermeister Spring which receives water from at least two losing streams draining the site.

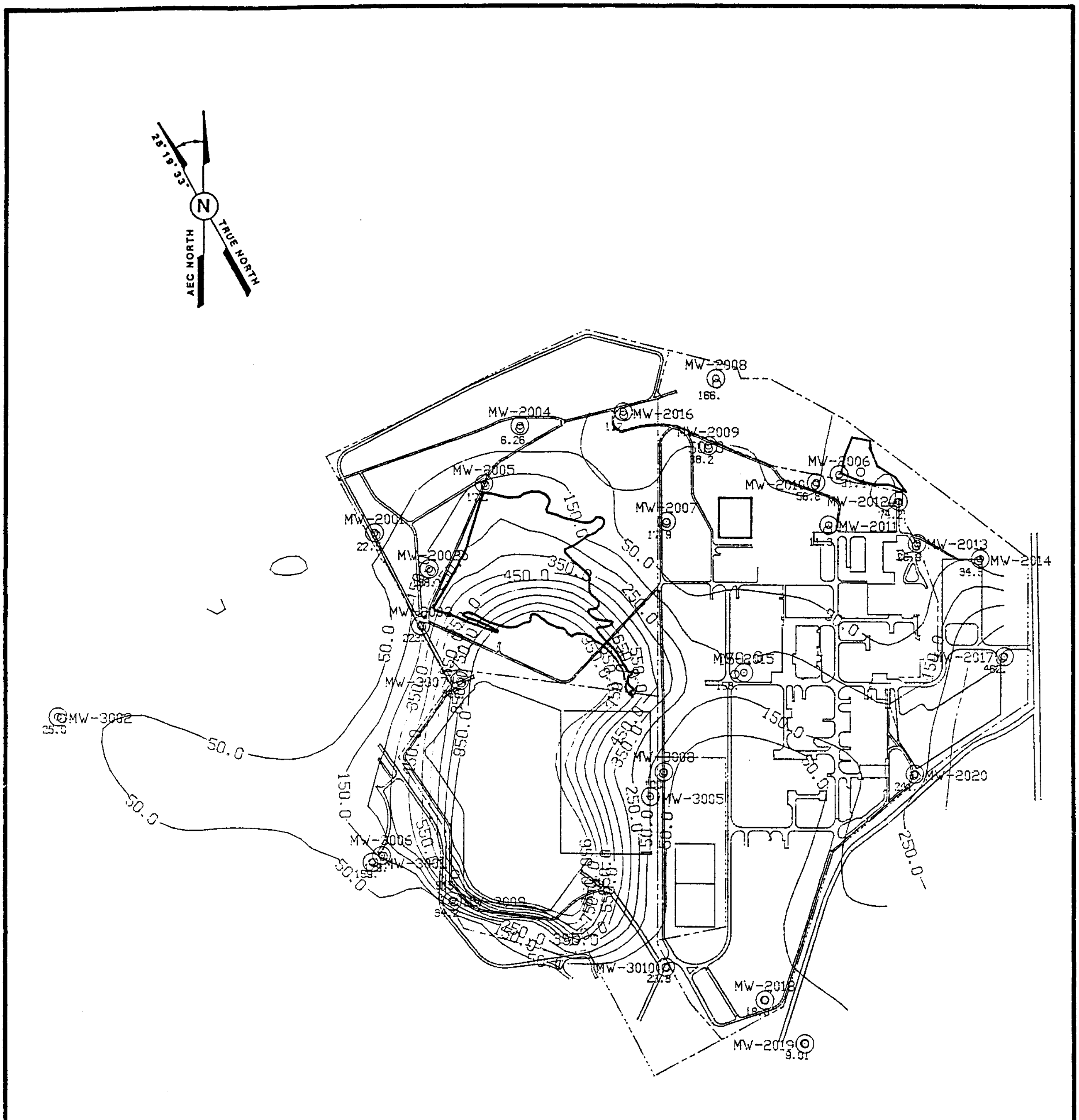


FIGURE 1-29

SULFATE ISOPLETH - PHASE I WATER QUALITY REPORT

MK FERGUSON-1987

TABLE 1-14

NITROAROMATIC CONCENTRATIONS IN THE GROUNDWATER AT THE WSCP/WSRP

Sample No.	Date Sampled	2,4,6-TNT (ug/L)	2,4 DNT (ug/L)	2,6 DNT (ug/L)	Nitro benzene (ug/L)	1,3,5-Trinitro benzene (ug/L)	1,3-Dinitro benzene (ug/L)
MW-2001	3/3/87	<0.5	2.1	2.4	1.0	0.05	<0.4
MW-2002	3/4/87	0.6	<0.2	<0.6	<0.6	<0.03	<0.4
MW-2003	3/4/87	<0.5	0.3	0.7	<0.6	<0.03	<0.4
MW-2003-D	3/4/87	<0.5	0.4	0.7	<0.6	<0.03	<0.4
MW-2004	3/3/87	<0.5	<0.2	0.6	<0.6	<0.03	<0.4
MW-2005	3/5/87	<0.5	0.4	0.9	<0.6	0.1	<0.4
MW-2006	3/2/87	<0.5	3.7	50.1	8.3	4.6	0.5
MW-2007	3/2/87	<0.5	0.3	<0.6	<0.6	<0.03	<0.4
MW-2008	3/4/87	<0.5	<0.2	<0.6	<0.6	0.04	<0.4
MW-2009	3/3/87	<0.5	0.4	0.9	0.6	<0.03	<0.4
MW-2010	3/3/87	1.7	0.3	0.9	<0.6	0.06	<0.4
MW-2011	3/3/87	<0.5	2.2	25.8	<0.6	<0.05	<0.4
MW-2012	3/3/87	1.8	1.3	<0.6	<0.6	0.6	<0.4
MW-2013	3/2/87	29	172	138	<0.6	4.9	0.5
MW-2014	3/2/87	<0.5	1.1	1.5	4.0	0.6	<0.4
MW-2015	3/6/87	<0.5	0.2	<0.6	<0.6	<0.03	<0.4
MW-2015-D	3/6/87	<0.5	<0.2	<0.6	<0.6	<0.03	<0.4
MW-2016	3/4/87	<0.5	<0.2	1.0	<0.6	<0.03	<0.4
MW-2017	3/2/87	<0.5	0.2	<0.6	<0.6	<0.03	<0.4
MW-2018	3/5/87	<0.5	<0.2	<0.6	<0.6	<0.03	<0.4
MW-2020	3/6/87	<0.5	0.2	<0.6	1.7	<0.03	<0.4
MW-3007	3/4/87	<0.5	1.8	3.3	<0.6	0.1	<0.4
MW-3008	3/10/87	<0.5	0.4	<0.6	<0.6	<0.03	<0.4
MW-3009	3/5/87	<0.5	0.5	<0.6	<0.6	0.05	<0.4
MW-3010	3/5/87	<0.5	<0.2	<0.6	<0.6	<0.03	<0.4
MW-3010-D	3/5/87	<0.5	<0.2	<0.6	<0.6	<0.03	<0.4
MW-3013	3/5/87	<0.5	0.3	<0.6	<0.6	<0.03	<0.4
MW-4001	3/5/87	37	1.4	4.2	<0.6	18.3	<0.4
MW-4002	3/6/87	2.7	0.7	1.3	<0.6	<0.03	<0.4
MW-4003	3/6/87	<0.5	0.3	0.8	<0.6	<0.03	<0.4
MW-4006	3/5/87	1.2	<0.2	3.0	2.5	1.7	<0.4
MW-4019	3/6/87	<0.5	0.2	<0.6	<0.6	<0.03	<0.4

Note: Nitroaromatics Analysis Following USATHAMA Method (HPLC)

Besides detecting the previously described contamination, the Phase I Water Quality Assessment established the absence of organic (other than nitroaromatics) and significant metals contamination in WSCP/WSRP groundwater. Due to limited organic compound usage in processes at the WSCP/WSRP, their absence in groundwater was expected.

The Phase I Water Quality Assessment detected groundwater contamination and has partially defined the horizontal extent. Additional investigations are required to define the horizontal and vertical extent of contamination, define aquifer properties, and establish chemical contamination source areas.

1.3 CONCEPTUAL MODEL

Data collected from prior and current sampling operations, including that presented in the Phase I Water Quality Assessment Report (MKF, 1987), have been subjected to QA/QC evaluation. Those data evaluated for adequacy and validity have been utilized, with the incorporation of available areal geological, hydrological, climatological and other information as presented in Section 1.2 of this report, to establish the physical and chemical characteristics of the site and used to construct a conceptual model to describe the WSS.

The hydrogeological components of this WSCP/WSRP model illustrate the following known and potential groundwater and surface water contaminants, their sources, known affected aquifers and surface impoundments, routes of migration, and potential receptors.

- o Potential or known contaminants are:

    1) Radiological constituents, including radium-226, radium-228, thorium-230, thorium-232 and uranium.
    2) Inorganic anions including nitrates, sulfates, and fluoride

3) Nitroaromatics, primarily 2,6-DNT, 2,4-DNT, 2,4,6 TNT and 1,3,5 Trinitrobenzene.

- o Potential or known sources include the WSRP, WSCP, Ash Pond, Frog Pond, and drainage from the plant area and nearby properties. Source areas are depicted on Figures 1-24 to 1-26.
- o Potential affected aquifers are the fractured and solutioned limestones, other consolidated sediments, and unconsolidated sands and gravels deposited in stream valleys. These are depicted on Figure 1-30.
- o Potential migration routes include surface drainage ways from the site, pervious and semi-pervious zones in the unconsolidated overburden that mantles bedrock, and the fractured and solutioned limestone bedrock which underlies the WSS as depicted on Figures 1-10 to 1-13, 1-30, and 1-31.
- o Potential receptors include users of the Busch Wildlife Lakes, and the local streams, springs, and wells serving nearby farms, rural homes, schools, and local communities. (A detailed exposure evaluation will be presented in the RI/FS work plan.)

Significant preliminary conclusions can be interpreted from this model. They are:

1) A N-NE trending groundwater divide traverses the eastern third of the WSS. Groundwater flow is primarily northwest and southeast away from the divide toward the Mississippi and Missouri rivers, respectively.

2) Perched and mounded groundwater zones are present in the vicinity of the raffinate pits, which suggests leakage at these pits and variable horizontal and vertical hydraulic conductivities in the overburden materials.

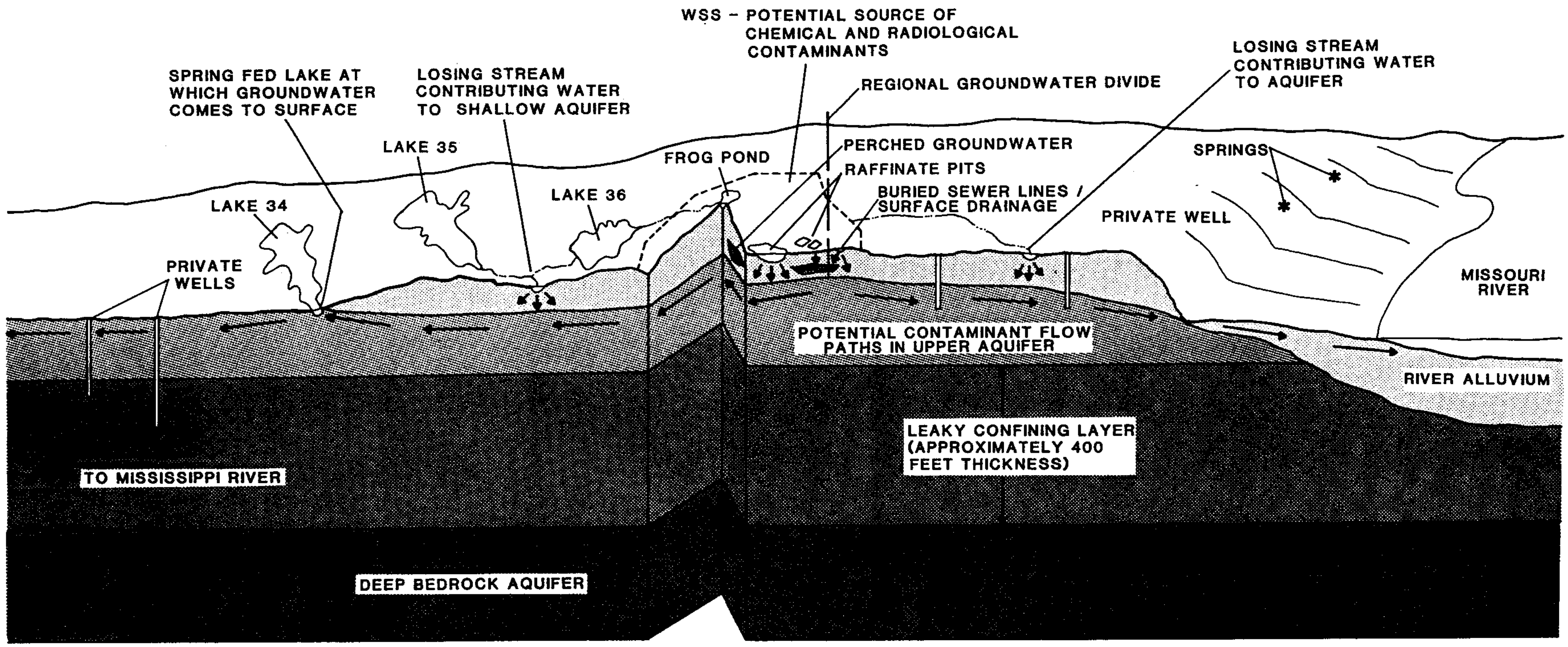


FIGURE 1-30

PRELIMINARY ILLUSTRATION FROM THE WSS OF POTENTIAL SUBSURFACE FLOW PATHS

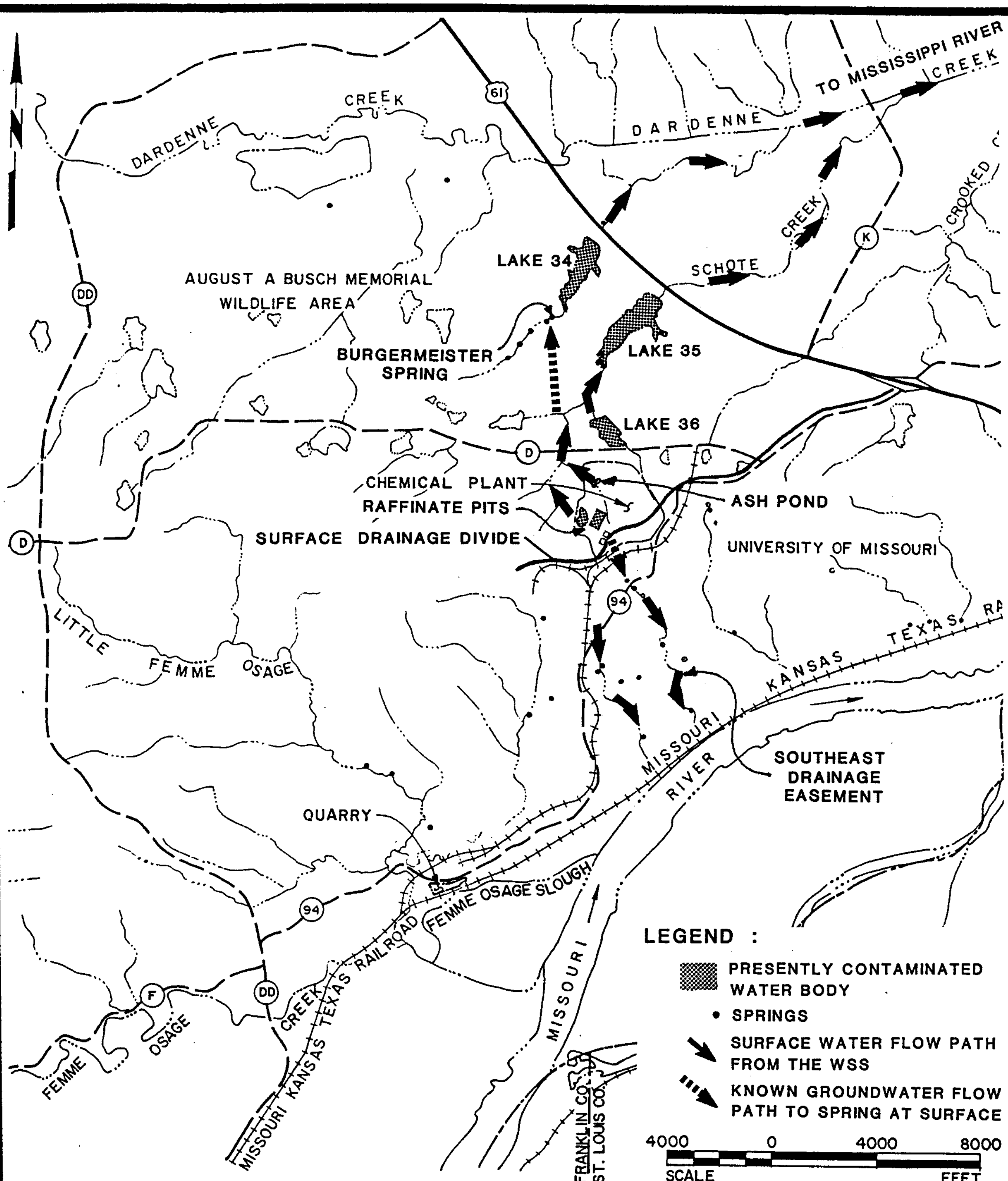


FIGURE 1-31

PRELIMINARY ILLUSTRATION OF POTENTIAL SURFACE FLOW PATHS FROM THE WSS

3) The raffinate pits appear to be contributing nitrates, sulfates, and dissolved metals to the groundwater. Nitrate contaminated groundwater is issuing from Burgermeister Spring, approximately 7000 feet north of Raffinate Pit 3, a possible source.

4) Nitroaromatics and radiological constituents are also present at Burgermeister Spring. The probable sources are surface waters from Ash Pond and other areas of the WSCP.

5) The major groundwater aquifer to be affected by contaminants and to allow contaminant transport is the upper weathered and fractured zone of the Burlington/Keokuk Formation.

6) Vertical migration of contaminants will be impeded by a thick sequence of sedimentary rocks, classified by the USGS (1986) as a leaky confining bed of low hydraulic conductivity. These rocks, including the Kimmswick Limestone, shales in the Decorah Formation, and underlying Ordovician siltstone, limestones and dolomites, would tend to preclude contamination of deep productive aquifers, e.g. St. Peter Sandstone.

7) Surface water pathways and storm sewers present at the site (e.g. Southeast Drainage Easement; Frog Pond and Ash Pond spillways and appurtenances) contribute contaminants to groundwater and surface waters (e.g. Busch Wildlife Lakes).

8) Overburden, or unconsolidated materials, mantles WSS bedrock units. It ranges in thickness from 20 to more than 55 feet and has variable chemical and physical characteristics. Those gravelly clay and silt materials at the overburden-bedrock contact are classified as residuum and are the result of bedrock weathering and erosion.

9) Surface water features displaying hydraulic connection to groundwater contaminant migration pathways are Burgermeister Spring, Busch Wildlife Lakes No. 34, 35, and 36, the Southeast Drainage Easement and associated springs.

The preliminary conceptual model of the site has utilized the hydrogeologic data obtained from previous sampling operations. Data obtained from future sampling activities described in this plan (Section 2.0) will be incorporated into the conceptual model which, upon refinement, will allow for a better definition of site conditions. This refined conceptual model and more sophisticated computer models more thoroughly portray:

- The physical characteristics of the site, i.e. the environmental setting, surface features, hydrology, geology, meteorology, overburden and aquifer parameters, contaminant pathways, and other factors related to the hydrogeologic regime.

- The source of contaminants and the chemical and physical characteristics of that source.

- The nature and extent (horizontal and vertical) of contamination. This is established after an analysis of physical, chemical, and source studies described above and includes analysis with the use of computer models. Additional data relating to contaminant release times and rate of migration will be incorporated into these models.

1.4 DATA USES/NEEDS

Previous sections of this Hydrogeologic Investigation Sampling Plan have described known existing conditions on the site and have partially defined areas or investigative categories where data are deficient. The EPA has provided guidelines and requirements through the Data Quality Objective (DQO) process (Data Quality Objectives for Remedial Response Activities, 540/G-87/003, March 1987) and RI/FS guidance documents for the delineation of data uses and needs.

Analysis of existing data under the DQO process, as applied on the Weldon Spring Project, has provided for: 1) a limited physical and chemical characterization of the site; 2) the construction of a preliminary conceptual model; 3) the identification of data needs and uses; and 4) the initial scoping of additional sampling and data collection activities. A component of the process includes the identification of potential remedial technologies. At the WSS there has been a preliminary delineation of possible hydrogeologic-related Expedited Response Actions (ERA's), e.g., construction of drainage dikes, design and construction of contaminated water treatment plants, and removal of possible contaminant sources. Selected ERA's have been submitted to EPA for approval as Interim Response Actions (IRA's).

General data use categories, such as risk assessment and remedial design, are presented in the DQO manuals. These categories are applicable for the Weldon Spring Project and previous investigations have provided information for the following RI/FS hydrogeologic or other related components: 1) site characterization; 2) health and safety; 3) risk assessment; 4) remedial alternatives evaluation and design (including expedited response actions); and 5) community relations plans. Additional data collection activities conducted at the WSS will provide information for the refinement or revision of the foregoing RI/FS use categories.

Section 2.0 describes sample collection and rationale for the various components of the program. Listed below are the data needs and rationale for correcting data deficiencies on the WSS, as follows:

- The surface hydrology of the site and vicinity has been partially defined. Additional data pertaining to possible contaminant transport mechanisms, source areas, stream recharge/discharge and pond storage capacity are needed to fully define the hydrogeological regime. Data gathered from this study will also be included as a component of the water balance study which will be incorporated into USGS computer models of the site.

- A review of the available climatologic data indicates site-specific climatologic data are lacking. Extension of this data base to include precipitation, temperature, evaporation, wind, and relative humidity will be needed for water balance and contaminant migration studies.

- The geologic investigation will further define the bedrock geology at the site and immediate vicinity for zones underlying the upper portion of the Burlington/Keokuk Formation. More data on the competency of the lower unit of the Burlington/Keokuk will be obtained. Site-specific data on underlying bedrock units are needed for definition of thicknesses, physical character, and potential migration pathways, including further definition of solution channels and impervious strata or zones. Specific lithologic data and potentiometric head data on Ordovician and Devonian formations underlying the Burlington/Keokuk Formation is needed to define direction of groundwater movement.

- The thickness of the overburden units is well defined. The physical properties affecting water and contaminant presence, movement, storage, and migration in the vadose zone require additional definition and verification. These data are needed for determination of the effect of the overburden materials in immobilizing, attenuating, or slowing contaminant transport. Also, localized saturated contaminated lenses have been identified in the overburden in the raffinate pit area. Geophysical surveys have identified other potential contaminated zones. Additional data are needed to fully define the nature and extent of these zones.

- Two groundwater flow regimes are prevalent on the WSS, i.e. Darcian flow and conduit flow. Numerous studies have been completed within both groundwater flow regimes. Definitive modeling of groundwater flow and contaminant migration specific to each regime has not been completed. Aquifer parameters have not been defined. Hence, field tests are needed to provide hydraulic conductivity, transmissivity, storativity, and recharge/discharge data. For the conduit flow regime, specific site-related connections to several discharge points have been verified. A more thorough inventory of potential discharge points and verification of any additional site-related connections is needed. Refinement of the predictive models of the groundwater migration pathway will improve understanding of the impact of groundwater contamination and facilitate the endangerment assessment.

- The karst hydrogeology needs to be fully characterized. Seeps, springs, solution cavities, channels, and possible ancestral sink areas need to be defined as they are potential conduits for contaminant flow to nearby surface impoundments, e.g. Lake 36 on Busch Wildlife Area, and to springs.

- Several groundwater contaminant plumes have been identified beneath and in the vicinity of the site. Refinement and definition of the lateral and vertical extent of these plumes is needed. Data are lacking to confirm which nearby areas are not affected.

- The Water Quality Phase I Assessment Report (MKF Dec. 1987) recommends the acquisition of additional water quality data, including stream, lake, and groundwater sampling and analyses. These data, coupled with soil and sediment analyses, are needed to fully characterize existing and potential contamination and contaminant transport and fate.

1.5 SAMPLING PLAN OVERVIEW

There are eight major tasks designed to acquire the needed data described above. They are:

- Extend network of monitoring wells in order to determine vertical and horizontal extent of groundwater contamination, the levels of contamination, and the hydrogeologic conditions at the WSS.

- Perform aquifer testing to: (1) provide area and depth data on aquifer characteristics, such as hydraulic conductivity, transmissivity, and storativity; (2) to provide information for prediction of long-term contaminant migration; and (3) assess effects of pumping the upper limestone aquifer.

- Study the karst hydrogeology by including dye tracing and stream flow studies to determine groundwater/surface water interactions and improve understanding of migration pathways and rates of flow.

- Study surface water hydrology and water quality to: (1) define potential surface migration pathways; (2) determine the possible extent of migration; (3) measure concentrations of contaminants in surface water; and (4) define the hydrologic characteristics associated with the surface water features.

- Characterize unsaturated zone to: (1) define chemical and physical characteristics of the media for classifying types and levels of contaminants; (2) estimate recharge to the groundwater system; and (3) define perched zones that may influence contaminant migration.

- Perform hydrogeologic and water balance studies to define: (1) regional groundwater levels; (2) groundwater fluctuations; (3) features that influence groundwater movement and surface water/groundwater interaction; and (4) groundwater chemistry relationships.

- Develop computer models of the groundwater flow and contaminant transport in order to predict future contamination migration and evaluate the effectiveness of possible mitigation measures.

- Perform evaluation analyses from the above tasks and previous studies in order to accomplish the sampling plan objectives described in this section.

2.0 HYDROGEOLOGIC SUBTASKS

Complementary hydrogeologic investigations will be conducted by the WSSRAP, MDNR and the USGS on a site-specific and regional basis. The WSSRAP program (described in Sections 2.1 through 2.5) will investigate surface and subsurface hydrogeologic conditions at the WSS. The USGS will investigate regional groundwater flow, water balance, and water chemistry (as summarized in Section 2.6). Although the investigations will be performed independently by WSSRAP and the USGS, the programs have been designed cooperatively to be consistent, so that information from each study can be utilized for incorporation into a consistent interpretive model.

2.1 GROUNDWATER MONITORING

Groundwater monitoring is part of an integrated program designed to characterize the hydrogeologic regime at the Weldon Spring Site (WSS) and its immediate vicinity. Other aspects of this program are discussed in subsequent sections. The groundwater monitoring efforts described in this section will focus on the bedrock aquifer in the Burlington-Keokuk Formation.

Groundwater monitoring for Remedial Investigation (RI) activities will include installation and sampling of new monitoring wells as well as continued monitoring of existing wells. These efforts are designed to more accurately define the extent and magnitude of groundwater contamination which was indicated by previous studies (MK-F, 1987).

In the first quarter of 1987, Weldon Spring Site Remedial Action Project (WSSRAP) initiated an Environmental Monitoring Program. This program is more comprehensive than previous monitoring programs. Water quality monitoring includes: (1) sampling of monitoring wells primarily near the site perimeter; (2) sampling of surface water bodies potentially affected by runoff from the site; and (3) sampling of runoff under provisions of a NPDES permit.

A Phase I Water Quality Assessment conducted during March 1987 began assessing the overall quality of groundwater at the WSS. Results of the Phase I Water Quality Assessment indicated a plume of contaminated groundwater containing high nitrate and sulfate concentrations underlying the western half of the site and a plume containing high nitroaromatic concentrations in the northeast corner of the site. These results are discussed in detail in the Phase I Water Quality Assessment Report (December 1987) and summarized above in Section 1.2.10. Plans for additional groundwater monitoring, as discussed in the following sections, are based on results of the Phase I Water Quality Assessment and review and interpretation of other existing information.

2.1.1 Extended Monitoring Well Network

2.1.1.1 Existing Monitoring Wells

The existing monitoring wells described in this section will be retained to monitor water levels and groundwater contamination. Combined with the additional monitoring wells described in the following section, the existing wells will form an extended monitoring well network for determination of groundwater quality and flow parameters.

Locations of existing monitoring wells are illustrated on Figure 2-1. In order to provide a consistent identification system for existing and future monitoring wells, new 4-digit well numbers have been assigned to all existing wells. New and old well numbers, location coordinates (based on original AEC plant grid), depths, and other information are presented on Table 1-12. Monitoring wells to remain in service are listed on Table 2-1. The 26 monitoring wells to remain in service include only those

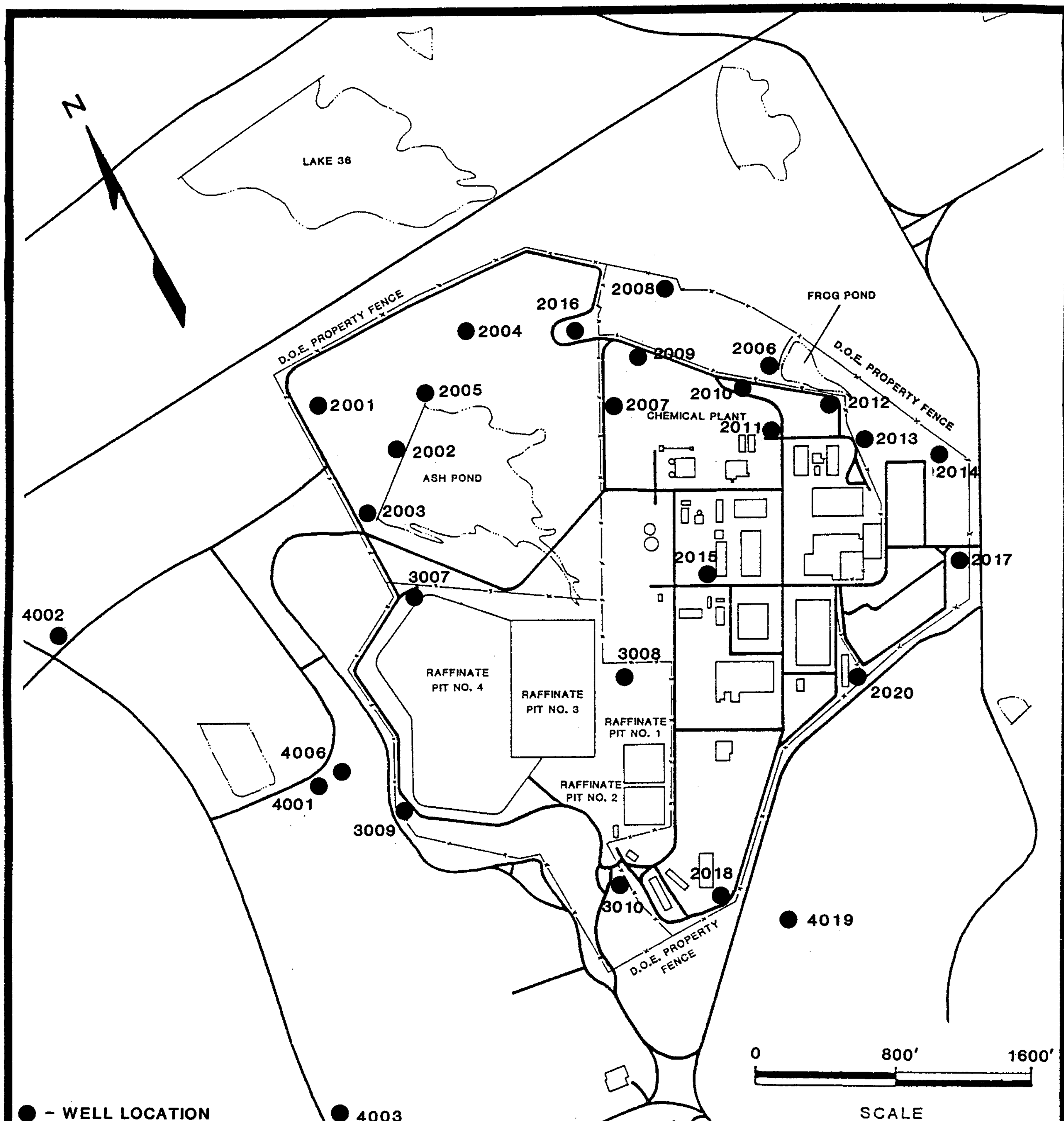


FIGURE 2-1

EXISTING MONITORING WELLS

TABLE 2-1

EXISTING MONITORING WELLS SUITABLE FOR CONTINUED MONITORING

MW-2001	MW-2011	MW-2020
MW-2002	MW-2012	MW-4001
MW-2003	MW-2013	MW-4002
MW-2004	MW-2014	MW-4003
MW-2005	MW-2015	MW-4006
MW-2006	MW-2017	MW-3008
MW-2007	MW-2018	MW-3009
MW-2008	MW-4019	MW-3010
MW-2009		
MW-2010		

wells which are suitable for water level measurements and groundwater sampling; wells that are dry, damaged, or destroyed are excluded. Monitoring wells with a 2000 series number are located within the chemical plant area, wells with a 3000 series number are located in the raffinate pits area, and wells with a 4000 series number are located outside of the site boundaries.

Of the 29 wells that were sampled for the Phase I Assessment study, 28 are screened in the bedrock aquifer. Existing monitoring wells are included in the extended monitoring well network based on the following criteria:

- o Complete lithologic log and construction details.
- o Screened in the bedrock aquifer.
- o Documentation of quality control/decontamination procedures.
- o Factory-slotted PVC or wire-wound stainless steel screens (open borehole in bedrock with casing grouted through the unconsolidated soils is of limited use, but acceptable).
- o Filter pack (sand or gravel) surrounding screen.
- o Bentonite seal above the filter pack.
- o Grout to surface.
- o Locking protective casing.

Existing monitoring wells that will be included in the extended monitoring well network were installed in 1983 (seven wells) and 1986 (nineteen wells) during hydrogeological studies by Bechtel National, Inc. (BNI).

Six of the monitoring wells installed in 1983 were constructed with 4-inch diameter PVC casing through the unconsolidated soil and an uncased open borehole in the bedrock. The six wells include: MW-2020, MW-4002, MW-4003, MW-3008, MW-3009, and MW-3010. Although groundwater samples and water level measurements can be collected from these wells, these samples and measurements are not representative of discrete zones within the aquifer. It is not possible to determine vertical flow patterns or vertical distribution of contaminants from these wells. Monitoring well MW-4006 was also installed in 1983 by BNI to a depth of 28.5 feet below ground level. This well was constructed with 2-inch PVC casing and has a 0.040-inch opening factory-slotted screen.

Monitoring wells MW-2001 thru MW-2015, MW-2017, MW-2018, MW-4019, and MW-4001 were installed in 1986 by BNI. These wells were constructed with 2-inch diameter, Type 316 L Schedule 40 stainless steel casing and .010-inch opening wire-wound screen. The wells are predominantly located in the upper, weathered portion of the Burlington-Keokuk Formation penetrating from 12 to 36 feet of saturated thickness.

Saturated overburden (perched and mounded conditions) will be addressed in Section 2.4, Overburden Hydrogeology; existing overburden wells are not included in the extended monitoring well network. Due to poor construction, two original wells (MW-2016 and MW-3007) were plugged and each was replaced with a two-well cluster.

Of the 26 remaining bedrock wells, 21 wells are located in the raffinate pits and chemical plant area, four wells are located outside the site boundaries in the Weldon Spring Training Area (WSTA) owned by the U.S. Department of the Army, and one well is located in the Weldon Spring Wildlife Area which is administered by the Missouri Department of Conservation.

2.1.1.2 Additional Monitoring Wells

Additional monitoring wells have recently been installed to further investigate the vertical and horizontal extent of groundwater contamination and characterize groundwater flow patterns. These wells are a component of the overall site characterization program initiated in 1988. Well installation was scheduled to allow for early acquisition of additional data. These supplementary data, incorporated into hydrogeologic and other models, will also allow for the delineation of additional data needs. It should be noted that these monitoring and pumping wells have been designed and placed to monitor and test the Darcian flow regime beneath and near the site. Darcian flow occurs through the pores and fine fractures in the bedrock formation and is considered the transport mechanism for the contaminant plumes beneath and in the vicinity of the site. Conduit flow occurs through enlarged or preferential fractures and conduits and is considered to be the transport mechanism for the contaminants found in off-site springs and seeps. The conduit flow regime will be investigated through dye tracing studies and off-site spring, seep, and stream monitoring discussed in Section 2.3.

Locations and depths of additional monitoring wells to complete the extended monitoring-well network have been selected to accomplish several goals:

- Critical areas will be monitored for horizontal and vertical contaminant migration. These areas include known contaminated areas, areas downgradient from contaminated areas, and areas in which contaminant migration is not expected, to confirm that it is not occurring.

- Monitoring wells are located in a consistent horizontal and vertical network. Wells are evenly spaced horizontally, and at depths related to those nearby upgradient wells, as described below.

- Well installation and sampling can be accomplished within a reasonable period of time.

The additional wells include: (1) deep wells installed in clusters with existing wells where elevated concentrations of contaminants have been detected; and (2) wells installed downgradient of the farthest documented extent of contaminant plumes to determine the horizontal extent of contamination.

Groundwater flow in the shallower, more highly weathered zones of the Burlington/Keokuk Formation is likely to be predominantly horizontal, eventually discharging to nearby springs and streams. The existing monitoring wells and additional shallow wells will effectively monitor this zone. A portion of the flow could also migrate to deeper zones within the aquifer below the elevation of the known discharge points. The deep monitoring wells are installed to monitor deeper zones below the apparent flow paths to springs and streams.

Locations of additional monitoring wells are shown on Figure 2-2. Criteria for the location of these wells include:

- All individual wells and well clusters have been located within 500 to 1000 feet of two or more other well or well-cluster locations to effectively map groundwater flow patterns by comparing three or more water-level elevations.

- Deep monitoring wells are located adjacent to selected wells in which contaminant concentrations above U.S. EPA Drinking Water Standards were detected in Phase I Water Quality Assessment samples.

- Screened intervals of deep monitoring wells are set approximately 50 feet below the screened intervals of adjacent shallow wells.

- Shallow wells are located downgradient from existing wells and areas with significant groundwater

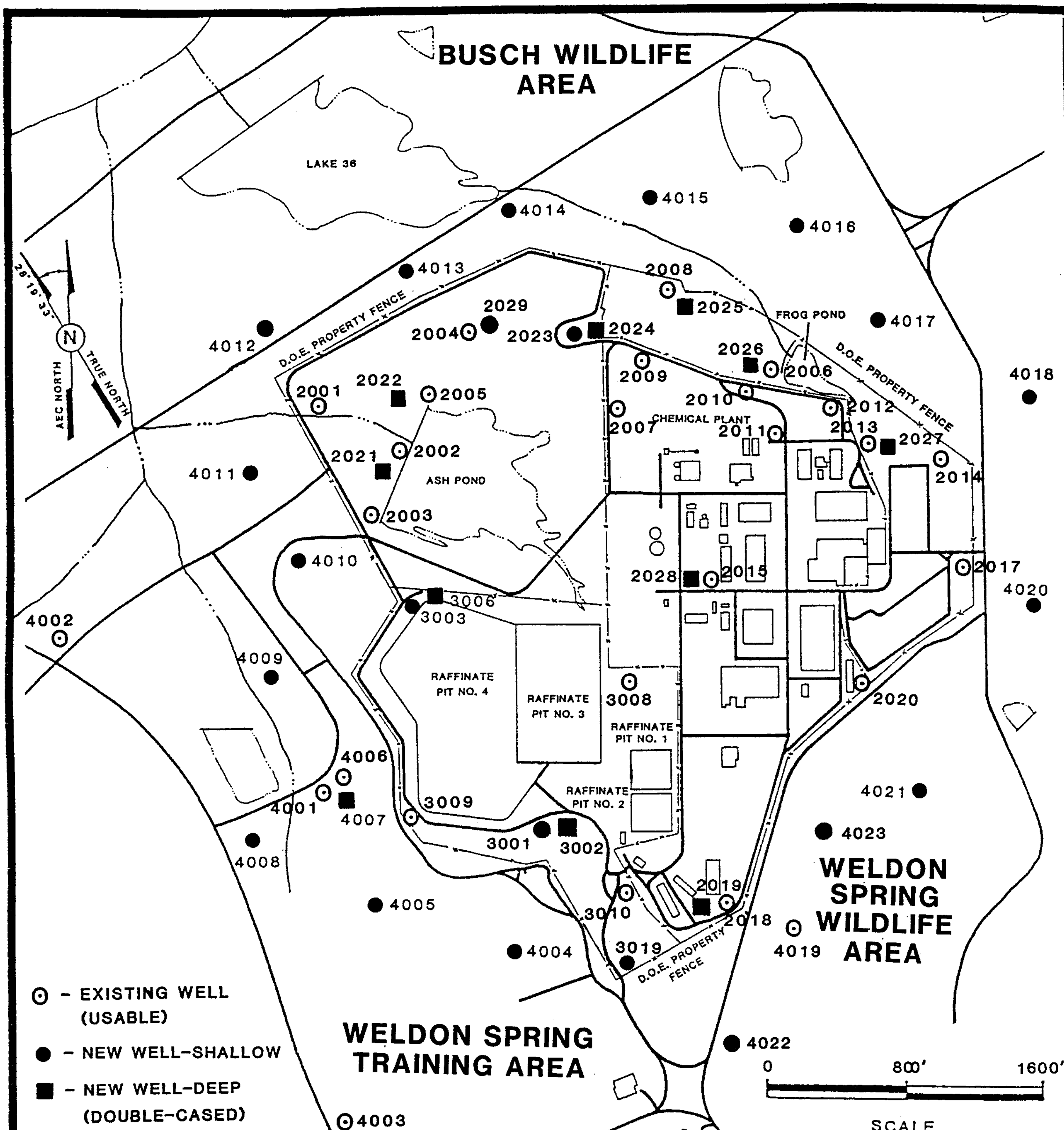


FIGURE 2-2

EXTENDED MONITORING WELL NETWORK

contamination.

- Screened intervals of shallow wells are set in permeable fractured zones of the bedrock aquifer as observed from downhole video surveys or as defined by an analysis of rock cores, water level data, and information obtained from nearby wells which have screened sections in permeable zones.

These criteria have been modified as necessary when selecting individual well locations and/or depths. A total of 33 new monitoring wells have been installed. This total includes 11 deep wells and 20 shallow wells. Rationale for well placement is presented in Table 2-2.

Two of the existing monitoring wells, MW-2016 and MW-3007 (Figure 2-1), have been plugged and replaced with two-well clusters. MW-3007 has an open borehole extending through approximately 54 feet of saturated thickness in the bedrock. The highest nitrate concentrations in the Phase I Water Quality Assessment were detected in this well. MW-2016 was constructed using 2-inch diameter PVC casing with a screen 7 feet in length and a filter pack 88 feet in length. This well is the deepest of the existing monitoring wells and also had a high nitrate concentration during the Phase I Water Quality Assessment. At each of these locations, it is critical to establish the depth of nitrate contamination and to measure the vertical gradients which could be producing downward migration of contaminants. The clustered replacement wells, each monitoring a discrete depth interval, will allow these determinations.

The locations of the additional monitoring wells placed downgradient from wells with known groundwater contamination have been selected anticipating that they will be beyond the extent of contaminant plumes. This selection was based on the known distribution of groundwater contamination and assuming Darcian

Table 2-2

ADDITIONAL MONITORING WELLS

LOCATIONS AND RATIONALE

WELL NUMBER	LOCATION	RATIONALE
MW-2019	Clustered with MW-2018 at southern end of site	Deep well to monitor vertical gradients and vertical extent of contamination detected in MW-2018
MW-2021	Clustered with MW-2002 to the north of Ash Pond	Deep well to monitor vertical gradients and vertical extent of contamination detected in MW-2002
MW-2022	Clustered with MW-2005 at northeast corner of Ash Pond	Deep well to monitor vertical gradients and vertical extent of contamination detected in MW-2005
MW-2023	Northern edge of site, midway between Frog Pond and Ash Pond; at location of MW-2016 (B-3)	Monitor contamination detected in MW-2016; MW-2016 will be replaced by 2-well cluster to monitor discrete shallow and deep intervals
MW-2024	Clustered with MW-2023 as described above	Deep well to monitor vertical gradients and vertical extent of contamination at this location
MW-2025	Clustered with MW-2008 on northeast edge of site	Deep well to monitor vertical gradients and vertical extent of contamination at this location
MW-2026	Clustered with MW-2006 on north side of Frog Pond	Deep well to monitor vertical gradients and vertical extent of nitroaromatic contamination detected in MW-2006
MW-2027	Clustered with MW-2013 approximately 500 feet south of Frog Pond	Deep well to monitor vertical gradients and vertical extent of nitroaromatic contamination detected in MW-2013
MW-2028	Clustered with MW-2015 near center of Chemical Plant Area	Deep well to provide vertical gradient data from center of monitoring well network near apparent groundwater flow divide; document presence or absence of contamination in deeper zones
MW-2029	Clustered with MW-2004 between Ash Pond and DOE Property Fence	Anomalously low nitrate concentrations detected in MW-2004, which penetrates only 18 feet of saturated thickness. MW-2029 installed to determine presence or absence of contamination at slightly greater depths, still within upper zone of aquifer

Table 2-2

ADDITIONAL MONITORING WELLS

LOCATIONS AND RATIONALE

WELL NUMBER	LOCATION	RATIONALE
MW-3001	Southern end of Raffinate Pit 3	Detect potential contamination and monitor water levels in center of Raffinate Pits Area
MW-3002	Clustered with MW-3001 at southern end of Raffinate Pit 3	Deep well to provide vertical gradient data in center of Raffinate Pits Area; detect potential contamination in deeper zones
MW-3003	Northern end of Raffinate Pit 4, at location of MW-3007 (B-17)	Monitor contamination previously detected in MW-3007; MW-3008 has been replaced by 2-well cluster monitoring discrete shallow and deep intervals
MW-3006	Clustered with MW-3003 as described above	Deep well to monitor vertical gradients and vertical extent of contamination previously detected in MW-3007
MW-3019	Southern end of site, approximately 500 feet west of MW-2018/MW-2019 cluster, approximately 500 feet southwest of MW-3010	Detect contaminant migration from immediate vicinity of MW-3010; define contaminant levels and flow patterns near apparent groundwater flow divide
MW-4004	Southwest of site boundary along Raffinate Pits, approximately 600 feet west of MW-3010	Detect westward extent of contaminant migration in conjunction with other monitoring wells beyond southwestern edge of site
MW-4005	Southwest of site boundary along Raffinate Pits, approximately 500 feet southwest of MW-3009	Detect westward extent of contaminant migration in conjunction with other monitoring wells beyond southwestern edge of site
MW-4007	Clustered with MW-4001 west of Raffinate Pit 4	Deep well to monitor vertical gradients and vertical extent of contamination detected in MW-4001
MW-4008	Southwest of site boundary along Raffinate Pits; approximately 500 feet west of MW-4001/MW-4007 cluster	Detect westward extent of migration of contaminants detected in MW-4001

Table 2-2

ADDITIONAL MONITORING WELLS

LOCATIONS AND RATIONALE

WELL NUMBER	LOCATION	RATIONALE
MW-4009	Beyond site boundary west of Raffinate Pits Area, approximately 800 feet north of MW-4001/MW4007 cluster	Detect westward extent of contaminant migration in conjunction with other monitoring wells
MW-4010	Beyond site boundary west of Ash Pond, approximately 600 feet northwest of MW-3003/MW-3006 cluster	Detect westward extent of contaminant migration in conjunction with other monitoring wells to west of site
MW-4011	Approximately 800 feet west-northwest of MW-2002/MW-2021 cluster	Monitor extent of contaminant migration in the upper part of Burlington-Keokuk aquifer from Raffinate Pits and Ash Pond area
MW-4012	Outside northern corner of site near Highway D	Detect northward extent of contaminant migration in conjunction with other downgradient wells
MW-4013	Near Highway D along northern edge of site, approximately 800 feet north-northwest of MW-2005/MW-2022 cluster	Detect northward extent of contaminant migration in conjunction with other downgradient wells
MW-4014	North of site boundary near Highway D and drainage from Frog Pond to Lake 36, approximately 800 feet north of MW-2023/MW-2024 cluster	Detect northward extent of contaminant migration in conjunction with other downgradient wells
MW-4015	North of site boundary and north of the drainage from Frog Pond to Lake 36, approximately 600 feet north of MW-2008/MW-2025 cluster	Detect north and northeastward extent of contaminant migration; possibly delineate eastern edge of contaminant plume
MW-4016	North of site boundary, approximately 1000 feet north of Frog Pond	Detect north and northeastward extent of contaminant migration from Frog Pond Area; possibly delineate eastern edge of contaminant plume

Table 2-2

ADDITIONAL MONITORING WELLS

LOCATIONS AND RATIONALE

WELL NUMBER	LOCATION	RATIONALE
MW-4017	North of site boundary, approximately 500 feet east-northeast of Frog Pond	Detect northeastward extent of contaminant migration from Frog Pond Area; detect contamination in immediate vicinity of former Ordnance Works waste impoundment
MW-4018	Beyond northeastern corner of site, on east side of Highway 94, approximately 800 feet east of MW-2013/MW-2027 cluster	Detect contaminant migration east and south from Frog Pond Area; further delineate groundwater flow divide
MW-4020	East of site boundary on east side of Highway 94, approximately 600 feet south-southeast of MW-2017	Detect potential contaminant migration to the southeast; define groundwater flow patterns and gradients southeast of site
MW-4021	Southeast of site boundary, approximately 1000 feet south of MW-2020, between site boundary and Highway 94	Detect potential contaminant migration to the southeast; define flow patterns and gradients southeast of site
MW-4022	Southeast of southern end of site, approximately 800 feet south of MW-2018/MW-2019 cluster, between site boundary and Highway 94	Detect potential migration to the southeast of contamination detected in MW-2018 and MW-3010; define groundwater flow patterns
MW-4023	East of southern end of site. Approximately 800 feet southwest of MW-4021.	Detect potential contaminant migration at the upper end of the southeast drainage. MW-2020, approximately 1000 feet north has yielded samples which indicate the presence of uranium in the groundwater

flow conditions in an equivalent porous medium. Small fractures were observed during downhole video surveys. No major fractures or conduits were observed.

Although it is anticipated that the additional wells will provide "negative documentation" serving to delineate the limits of contaminant plumes, it is possible that some of the additional wells may have elevated concentrations of contaminants. Such conditions could occur due to migration of a contaminant plume further than anticipated, or "breakthrough" of contaminants through zones of higher permeability. If such conditions occur, additional monitoring wells may be installed to monitor contaminant migration in the specific areas affected. Installation of additional downgradient wells is not warranted at this time. The areas of potential contaminant migration beyond the planned extended monitoring-well network cannot readily be predicted. The hydrogeologic regime beyond the extended monitoring-well network may vary from on-site conditions in regard to Darcian vs. conduit flow conditions, gradients, and flow patterns. This is of particular concern to the north of the site where artificial lakes in the Busch Wildlife Area may produce mounding effects and recharge from losing streams could alter flow patterns. The necessity for installation of additional downgradient wells will be evaluated following receipt of initial sampling results from the extended monitoring-well network.

Similar considerations apply to monitoring of vertical distribution of contaminants utilizing the clustered monitoring wells. The monitoring-well clusters installed as part of the extended monitoring-well network will provide information on vertical distribution of contaminants and vertical gradients. The actual vertical extent of contamination and vertical gradients producing downward migration can only be determined following initial sampling and water level measurements.

Following receipt of the sampling results, the necessity for any additional deep monitoring wells will be evaluated.

2.1.2 Well Installation

Monitoring well drilling, installation, and development was performed in accordance with accepted procedures as discussed in the U.S. EPA RCRA Technical Enforcement Guidance Document (1986). Standard Operating Procedures have been developed for WSSRAP based on EPA guidelines. A supervising geologist was present to document well drilling, installation, and development.

2.1.2.1 Decontamination

All drill bits, drill rods, casing, well logging and measurement equipment, and miscellaneous hand tools were decontaminated by hot steam-cleaning prior to use and between boreholes. Equipment damageable by steam cleaning, e.g., video cameras, was rinsed with potable water from on-site supplies. The entire drilling rig was decontaminated upon arrival on-site, and upon completion of drilling activities. Interior portions of equipment, such as pumps and hoses, which are not accessible for cleaning with a steam-cleaner were thoroughly cleaned and flushed with potable water.

Screen and casing was also decontaminated inside and out by steam-cleaning and wrapped or covered. The screen and casing was stored above ground to avoid contact with potentially contaminated soils prior to installation.

All surge blocks, bailers, and other development equipment were decontaminated by steam-cleaning before development begins at each well.

2.1.2.2 Drilling Methods

Drilling has been performed using rotary techniques or a combination of hollow-stem auger and rotary techniques. A supervising geologist has recorded a lithologic log for each borehole. When drilling through unconsolidated soils at new locations, split-spoon samples have been collected at intervals of 5 feet. All contaminated cuttings not sampled for laboratory analysis were collected and retained on the site. In drilling the boreholes for shallow monitoring wells, a 7-inch minimum diameter borehole was drilled to the bedrock surface. The bedrock was then cored to define weathered - unweathered limestone contact (generally less than 100 feet below ground surface). After completion of coring, the boreholes were reamed to a final diameter of 8.5 inches. Table 1-12 lists well location coordinates, elevation, depth, and other relevant well data. The shallow wells were screened in the upper, weathered portion of the Burlington/Keokuk Formation, as defined by an analysis of cores and down-hole video surveys.

The deep monitoring wells were double-cased through zones of known groundwater contamination to prevent contaminants from being transported downward during drilling and well installation. A 12-inch diameter borehole was drilled to a depth of at least 10 feet below the depth of the adjacent well. A 10-inch diameter steel outer casing was placed in the borehole and the annular space outside of the casing sealed with cement-bentonite grout to surface. The bottom of the casing was backfilled with at least four feet of grout which was allowed to set for a minimum of 72 hours before work continued. The drilling sequence of coring and reaming continued through this outer casing to a depth ranging from 108 to 150 feet. The deep wells were screened in the unweathered portion of the Burlington-Keokuk Formation.

2.1.2.3 Monitoring Well Construction

Monitoring wells were constructed using Type 316 stainless steel, threaded, flush-jointed screen and casing. Shallow wells (generally less than 100 feet deep) were constructed using 2-inch inside diameter (ID) screen and casing. Deep wells were constructed using 4-inch ID screen and casing to assure that pumps and other sampling and measuring devices can be readily lowered into and removed from the wells. Screen was of wire-wound construction with 0.010-inch slots. Screen length was 10 feet. Only non-hydrocarbon-based lubricants, such as silicon or Teflon, were permitted for use on pipe threads or drilling rods.

Continuous bedrock cores were collected from the top of bedrock to the total depth of the borehole in the shallow wells. In the deep wells, coring of the bedrock commenced at the base of the outer casing and continued for the total depth of the hole. This method of coring assured a detailed and accurate log of the bedrock at each monitoring-well location. When drilling through the interval that was cased off in the deep monitoring wells, grab samples of the drill cuttings were collected at intervals of five feet as drilling proceeds. Cores were inspected by a geologist for the presence of fractures and voids. Drilling rates, fractures, and voids detected by the driller were noted.

The core samples will be used to determine bedrock lithology, mineralogy, permeability, porosity, and evidence of bedrock contamination. Because lithologic logs were already available, coring was not done in the replacement wells (MW2023, MW2024, MW3006, and MW3003) that are adjacent to the wells that were abandoned (MW3007 and MW2016).

The screen and casing were lowered into the borehole using centralizers to insure that the casing was plumb and centered in the borehole. A filter pack of coarse (20-40 mesh) sand was placed around the screen by tremie pipe to a point 2 to 4 feet above the top of the screen.

A bentonite pellet seal was placed above the filter pack. The minimum thickness was 3 feet of dry pellets. The pellets were allowed to set for at least one hour before work continued. The annular space was sealed to the frost level with cement/bentonite grout.

A steel protective casing was set in a 2.5-foot square concrete pad at ground surface. The protective casing has a gas vent installed and will be locked. The concrete pad has a minimum thickness of 6 inches and slopes away from the casing. Concrete extends down the borehole to the frost level. Three protective iron posts filled with concrete were installed approximately 3.5 feet from the protective casing and 120° apart.

Well-construction details are illustrated on Figure 2-3. Further details on well installation were stipulated in the drilling specifications developed for the drilling subcontractors.

2.1.2.4 Well Development

Monitoring well development was completed in September 1988. Development techniques included downhole pumps (hand-operated or mechanically driven), bailers, and double-tube air-lift devices. Any equipment placed down the well was constructed of stainless steel, teflon, PVC, or tygon. No glues, solvents, pipe dope, or adhesive tapes have been used on any development equipment which is placed down a well. All air-lift devices utilized a separate air line and discharge line and are operated in such a manner that air cannot be injected into the filter pack or formation. The air lines have an in-line oil filter between the compressor or air tank and the air line entering the well.

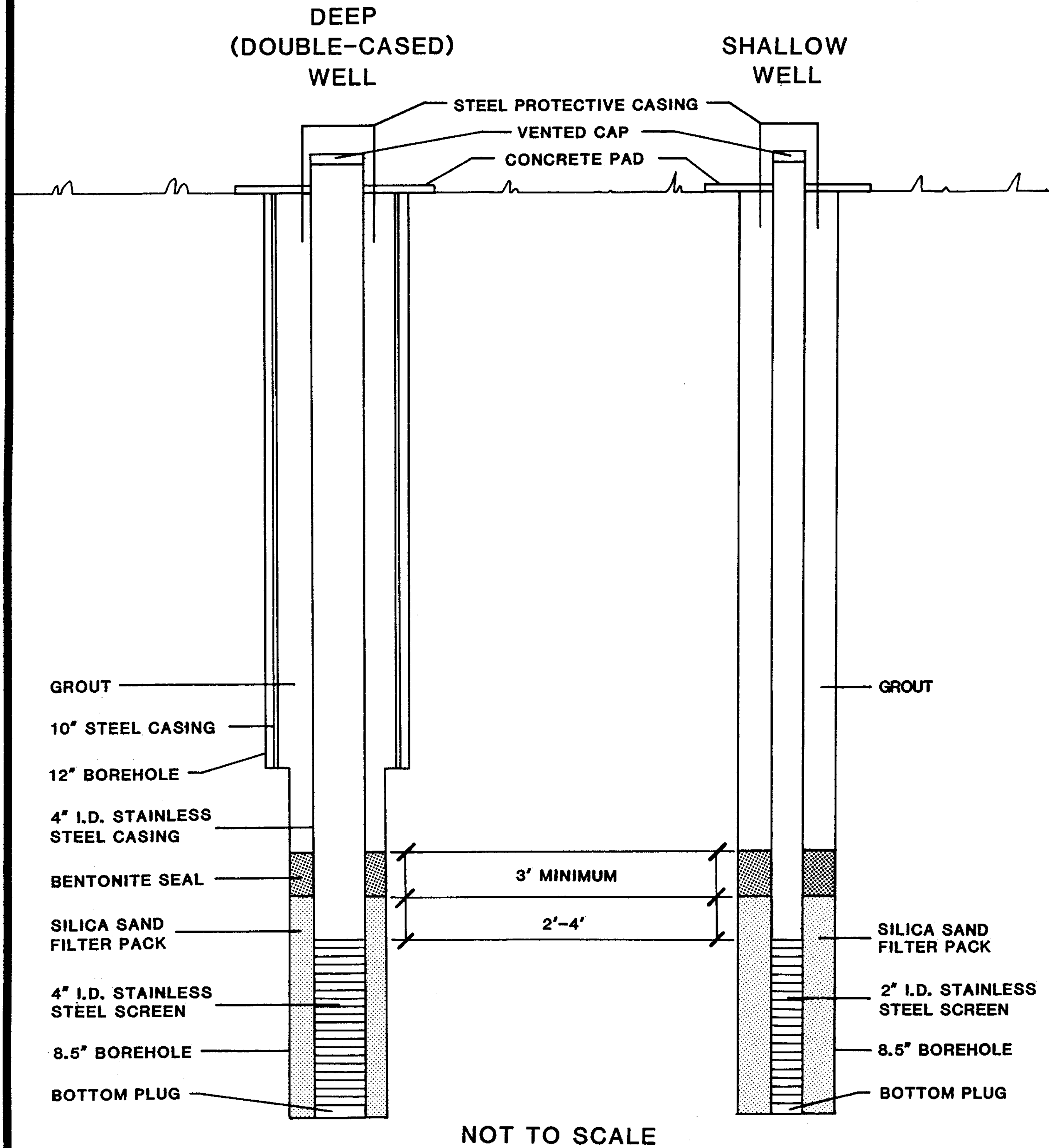


FIGURE 2-3

TYPICAL MONITORING WELL CONSTRUCTION

Each well was developed for a minimum of four hours or until clear, sediment-free water was produced as determined by the supervising hydrogeologist. The standard for clear, sediment-free water will be five Nephelometric Turbidity Units (NTU) determined by field or laboratory measurement. In all cases, a minimum of five volumes of standing water in the well and filter pack is being removed.

If water pumped from a monitoring well remains visibly turbid after five well volumes have been removed, measurements of pH, conductivity, and temperature were used to determine completeness of development. Three (3) additional volumes were then removed from each well. The pH, temperature, and conductivity were measured at the completion of removal of each well volume. For wells that were pumped or bailed dry and that recharge slowly, these measurements may be performed after completely purging the well after at least 50% recharge. Development was considered complete when three consecutive measurements showed conductivity to be stable within plus or minus 20%, pH stable within plus or minus 0.2 standard units, and temperature stable within 1 degree Celsius.

2.1.2.5 Abandonment of Wells and Boreholes

Any boreholes which were unsuitable for monitoring-well installation due to misalignment, contamination, lost drilling tools, or other reasons were abandoned by grouting.

Cement-bentonite grout was pumped into the borehole using a tremie pipe. The tremie pipe was placed initially at the bottom of the borehole and gradually raised as the borehole is grouted to the surface.

MW-2016 was abandoned by drilling out the PVC casing and filter pack using a four-inch minimum diameter roller bit. The borehole was then grouted to the surface as described above. The steel protective casing was removed.

MW-3007, which consists of an open borehole in bedrock with four-inch diameter PVC casing through the overburden, was abandoned by grouting as described above. The steel protective casing was removed.

2.1.3 Groundwater Sampling

Groundwater sampling will be performed in conjunction with and will expand the quarterly monitoring program described in the 1987 Environmental Monitoring Program Plan. At present, quarterly sampling is primarily concerned with monitoring of existing wells at the site perimeter to detect off-site migration of contaminants. For the remedial investigation, groundwater sampling will include the entire extended monitoring-well network including existing and additional wells as described above. The purpose of the sampling is to further define: (1) horizontal and vertical extent of contamination; (2) potential sources; (3) migration pathways; and (4) potential future contaminant migration.

2.1.3.1 Sampling Techniques

WSSRAP has developed detailed procedures for groundwater sampling and sample handling to insure that samples are representative and analytical results are accurate and defensible. The WSSRAP Environmental, Safety, and Health SOP No. 4.04.01 describes sampling equipment and step-by-step procedures for groundwater sample collection. These procedures are summarized below; the complete SOP is in the WSSRAP procedures manual as referenced in the Quality Assurance Program Plan (QAPP).

Submersible bladder pumps will be used for well purging and sample collection. Dedicated bladder pumps are in place in 20 existing monitoring wells which are sampled quarterly as part of the WSSRAP Environmental Monitoring Program. The pumps are constructed of stainless steel with Teflon bladders and Teflon lined discharge tubing. The new monitoring wells will be sampled using portable bladder pumps of similar construction which will be thoroughly decontaminated before reinstallation in monitoring wells.

Following two quarterly rounds of sampling from the extended monitoring-well network, additional dedicated bladder pumps will be installed, as appropriate, for future sampling operations. Five volumes of the well casing will be purged prior to sample collection. Field personnel will measure temperature, pH, and conductivity when beginning purging and immediately before sample collection. A SOP for each of these measurements is in the WSSRAP procedures manual as referenced in the QAPP. Samples will be collected in appropriate containers directly from the pump discharge. Samples will be placed in coolers immediately and will arrive at the laboratory within eight hours of collection. Groundwater sample labels, field forms, and chain-of-custody procedures are discussed in Section 3.3.

Internal quality control checks include checks on both laboratory and field activities. The QA/QC procedures for groundwater sampling have been developed in accordance with EPA protocols. Quality control samples for groundwater sampling will consist of duplicates, field blanks, and trip blanks.

Duplicate samples will be collected from 10 percent of the monitoring wells during each round of sampling. Duplicate samples will be collected and submitted for analysis at the same time as the original sample.

At least two field blanks will be collected during each round of groundwater sampling. These blanks will consist of distilled, deionized water pumped through the portable bladder pump, collected in the appropriate sample container, and submitted for analysis. These blanks will confirm the effectiveness of decontamination procedures and the absence of cross-contamination in sampling procedures.

Trip blanks will consist of distilled, deionized water placed in sample containers in the on-site laboratory, sealed, and transported with the samples in the field and to the laboratory.

2.1.3.2 Sample Analysis

All groundwater samples will be picked up and preserved on a daily basis by the analytical laboratory, metaTRACE, Inc. The lab is located in St. Louis County, Missouri and is approximately 20 miles from the WSS. Where applicable, the analytical procedures employed by metaTRACE will conform to CLP Methodologies. The laboratory procedures manual contains the analytical methods that will be followed and their respective detection limits.

Table 2-3 contains a listing of the analytical parameters, sample containers supplied by the laboratory, and the preservation methods used by the laboratory. The analytical parameters were selected based on the constituents detected by the Phase I Water Quality Assessment (1987). The radiologic parameters, nitroaromatics, and inorganic anions were either present at elevated concentrations in groundwater samples from the Phase I Water Quality Assessment or are present at on-site source areas.

2.1.4 Groundwater Level Monitoring

Static water levels will be measured monthly in all of the wells in the extended monitoring-well network. The water level measurements will be taken in accordance with SOP No. 4.04.02 located in the WSSRAP procedures manual as referenced in the QAPP. Generally measurement accuracy is achieved to 0.01 foot. Potentiometric surface elevations will be calculated from the

TABLE 2-3

GROUNDWATER SAMPLE ANALYSIS AND PRESERVATION

Analytical Parameter	Sample Container	Sample Preservative Used by Lab
TOC	1-8 oz amber jug	HCL to pH <2.0 and refrigerated
Inorganics		
Nitrate	1-500 ml polyethylene plastic jug	refrigerated
Sulfate		
Fluoride		
Chloride		
Total Dissolved Solids		
Nitroaromatics		
2,4,6 trinitrotoluene	1 gallon amber jug	refrigerated
2,4 dinitrotoluene		
2,6 dinitrotoluene		
1,3,5 trinitrobenzene		
1,3 dinitrobenzene		
Nitrobenzene		
RAD Parameters		
Natural uranium (dissolved)	1 gallon polyethylene plastic jug	HNO3 or HCL to pH <2.0 and refrigerated
Radium 226		
Radium 228		
Thorium 230		
Thorium 232		
Gross Alpha		
Gross Beta		

static water level measurements. Representative potentiometric surface maps will be constructed to illustrate the groundwater flow patterns present on site. Through interpretation of the data a more accurate delineation of the groundwater divide and of specific horizontal groundwater flow directions will be possible as well as seasonal or temporal changes in flow patterns. Additional refinement of the current understanding of the on-site recharge and discharge dynamics of the upper bedrock aquifer is also anticipated. Gradients on the potentiometric surface combined with interpretation of vertical gradients measured in the clustered wells will provide information regarding the hydraulic gradients on site.

2.2 AQUIFER TESTING

Aquifer testing will consist of single-well hydraulic conductivity (permeability) tests, and pumping tests to define the hydraulic characteristics of the aquifer to aid in predicting contaminant migration and assessing groundwater remediation alternatives.

2.2.1 Single-Well Hydraulic Conductivity Tests

Single-well hydraulic conductivity tests ("slug tests") will be performed to provide information on areal variations in permeability within the Burlington-Keokuk Formation.

2.2.1.1 Test Design

Slug tests will be performed in each new monitoring well installed as described in Section 2.1. These tests will also be performed in selected existing monitoring wells to verify the results of packer tests performed during well installation. Existing monitoring wells selected for slug tests are:

MW2002	MW2013
MW2005	MW2015
MW2006	MW2018
MW2008	MW4001

Criteria for selecting monitoring wells for slug testing were: 1) availability of packer test data on original boreholes; 2) presence of recently completed monitoring wells in close proximity to original boreholes; and 3) screened intervals of original and newly installed wells. These wells provide an evenly spaced distribution for confirming the packer test results. In addition, deep monitoring wells to be installed adjacent to each of these wells will be tested, allowing for comparison of hydraulic conductivity values at varying depths.

Slug tests are performed by displacing, adding or removing a known volume of water within the well. The volume change is produced as close to instantaneously as possible, and the volume is controlled to a premeasured amount. Readings of water levels within the well during the test will be made using a pressure transducer and electronic data logger, which will permit measurements to be made at one-second intervals during the early part of the test.

Slug tests, analyzed with formulae derived by Cooper, Bredehoeft, and Papadopulos, Ferris and Knowles, and Skibitzke, provide the most valid information when conducted in confined aquifers. In unconfined aquifers the Bouwer and Rice or Hvorslev procedures are applicable. In all cases, assumptions for application of formulae and analysis of data are not satisfied in the unconfined, anisotropic, fractured finite aquifer present on site. Also, slug testing procedures are applicable in an equivalent porous medium and are not valid if solution cavities exist and conduit flow is prevalent. Hydraulic conductivity values (K) yielded by slug tests primarily reflect K in horizontal directions. Therefore, only representative, approximate values are expected from slug tests on site.

Lohman (1979) suggests the applicability of slug testing in wells penetrating aquifers of rather low transmissivity, and presents a value of less than 7000 ft^2/day. At the Weldon Spring Site, an arbitrary upper hydraulic conductivity (K) limit for slug testing is considered to be on the order of 0.05 cm/sec. Formations with K values higher than 0.05 cm/sec will exhibit rapid recovery; hence, the acquisition of accurate recovery measurements is likely not feasible.

2.2.1.2 Test Performance

To begin the test, a pressure transducer will be installed in the well and static water level will be measured by wetted tape to calibrate pressure transducer readings. The water levels will be observed to ensure that the aquifer is under steady-state conditions. The volume change will take place within the well and water levels will then be measured as the well recovers to the static water level.

Slug tests will be performed by inserting a solid rod or similar object slightly smaller than the well diameter below the water level in the well in order to displace the water to a higher level. Water levels will be measured frequently as the water level falls to the original level. At this point the rod will be removed and water levels will be measured as the water level rises to the original level. The use of this test method allows for both falling head and rising head measurements. A tripod apparatus will be used to raise and lower the slug in the deep, 4-inch diameter monitoring wells.

Field measurements collected by the electronic data logger will be transferred to a computer data base. If warranted, after an analysis of data received from the slug tests, other tests such as borehole dilution and tracer tests may be deemed necessary to define aquifer parameters.

Borehole dilution or point dilution tests may be applicable to estimate linear velocity in selected wells. This test can be performed in a segment of the well screen which is isolated by packers. A tracer is introduced which is diluted by lateral groundwater flow which mixes and removes the tracer from the well bore. Dilution versus time relationship is determined and the linear velocity is computed by analytical formulae (Freeze and Cherry, 1979).

2.2.1.3 Data Analysis

The data will be analyzed to determine a hydraulic conductivity value using a standard formula such as the Hvorslev method. The hydrologic formula will be chosen to fit the conditions in the aquifer and well being tested. A qualified hydrogeologist will determine conditions of the aquifer and well, the formulae to be used, and the data points for the hydraulic conductivity calculation.

2.2.2 Pumping Tests

Long-term pumping tests will be performed at three locations on-site in order to determine aquifer properties such as transmissivity and specific yield. Also, anisotropic aquifers are prevalent at the Weldon Spring Site. The size, shape, orientation and spacing of fractures and the presence of solution cavities affect the aquifer yield and drawdown by distortion of the distribution of flow. The distortion is related to the distance to the observation wells, aquifer thickness, the ratio of the horizontal thickness, and vertical hydraulic conductivities and to the degree of aquifer penetration by the pumping well. Theoretical methods for determining hydraulic conductivity values from analysis of pumping test data have been developed (Kruseman and Ridder 1976). The results of long-term pumping tests will allow prediction of contaminant migration and assessment of the effects of pumping on groundwater flow patterns and contaminant levels. Pumping tests affect a much larger portion of the aquifer than the single-well tests and consequently yield more accurate hydraulic conductivity values. Transmissivity, specific yield, and anisotropy can be determined accurately only from pumping tests.

2.2.2.1 Pumping Test Design

Pumping tests have been designed based on the known characteristics of the Burlington-Keokuk Formation. The upper, weathered zone of the formation comprises an unconfined aquifer. Yields are expected to be relatively low, based on reported yields of 5-50 gallons per minute (gpm) for wells in this formation (USGS, 1986). Recently acquired data, on site, indicate well yield will be less than 10 gpm. Locations for pumping and observation wells are shown on Figure 2-4. The locations were selected to determine aquifer conditions in areas where contaminants have been detected in the groundwater and could potentially migrate off-site, and also at a location adjacent to the site proposed for the disposal facility for final remedial actions. Pumping Well 1 (PW-1) is located to the north of the apparent groundwater flow divide in the area where relatively high concentrations of nitroaromatic compounds were detected in groundwater samples. Pumping Well 2 (PW-2) is located adjacent to the proposed disposal facility near the southern end of the site. Results from the pumping tests at this location will allow for an assessment of aquifer conditions under this disposal cell site. The pumping and observation wells are located adjacent to, rather than within, the disposal cell area in order to minimize the number of wells and other boreholes within the disposal cell area that would need to be drilled out and grouted prior to disposal cell construction. Pumping Well 3 (PW-3) is located in the area where the highest nitrate concentrations were detected in groundwater samples from the

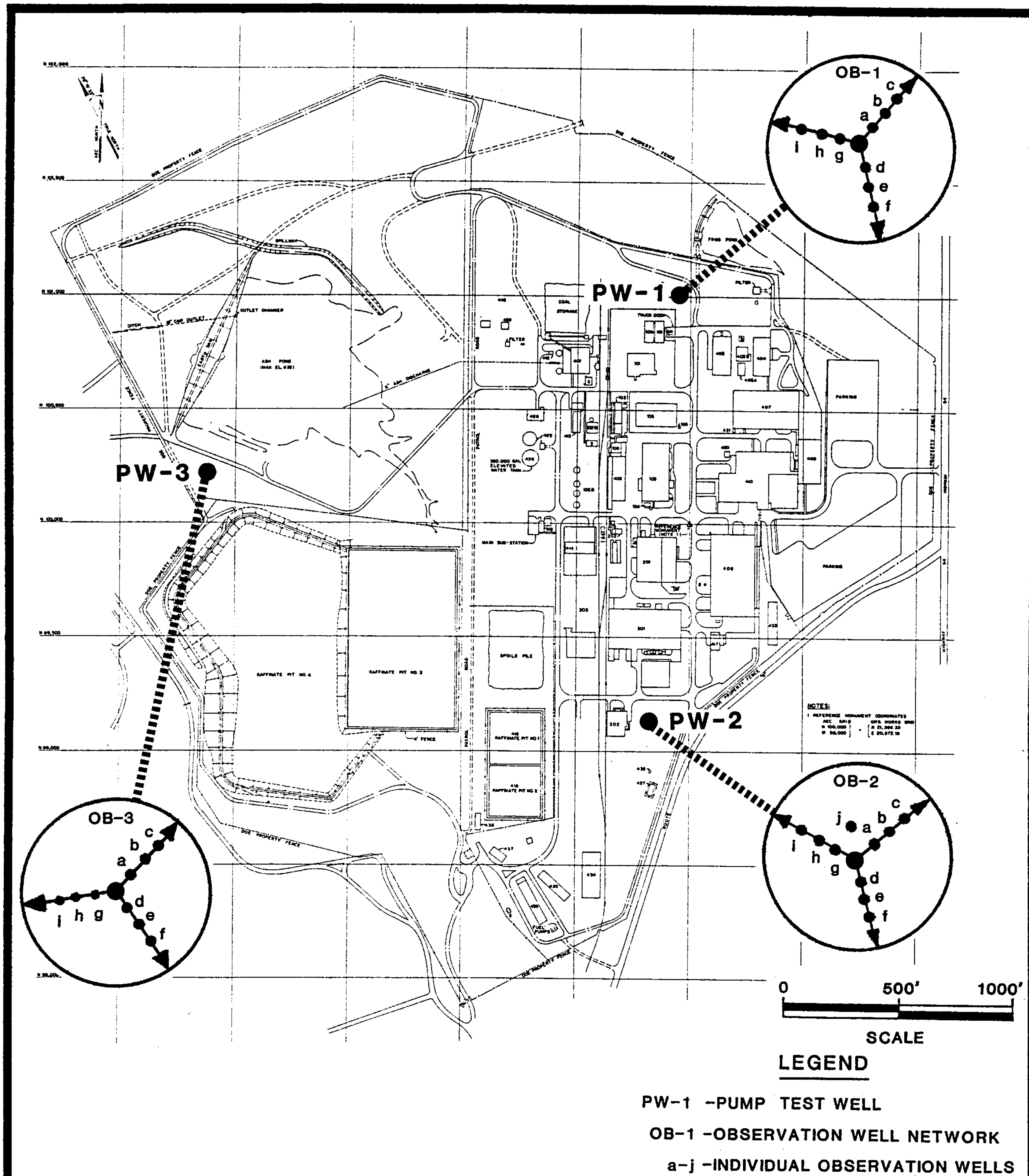


FIGURE 2-4

PUMPING AND OBSERVATION WELL LOCATIONS

Phase I Assessment.

The pumping wells are designed to be fully penetrating (continuously screened) through approximately 40 feet of saturated thickness of the Burlington-Keokuk Formation. This interval has been selected to encompass the weathered, more permeable zone in which groundwater contamination has been detected. This weathered zone will be defined from an analysis of cores and from observations by video survey. The test interval is limited to avoid providing vertical pathways through which contaminants could migrate into deeper zones in the aquifer when these wells are not being pumped. The fully screened interval will allow for the application of standardized techniques for pumping-test interpretation and calculations.

Each pumping test will utilize 9 or 10 observation wells oriented so as to determine the distribution of drawdown due to pumping of the aquifer. A set of nine observation wells, labeled "a" to "i" on Figure 2-4, have been completed at the same depth within the Burlington-Keokuk Formation, with the same screened interval as the pumping well. These wells are placed on three lines radiating from each pumping well with 120 degrees of arc between lines. One line is placed on a bearing of N60^{O}E, aligned with the predominant northeastward orientation of fractures in the Burlington-Keokuk Formation. The other two lines are located relative to this primary line. Following installation and development of the pumping well, a step-drawdown pumping test was performed to determine the optimum distance from the pumping well for placement of the observation wells and optimum pumping rate for long-term pumping tests. Water levels were measured in nearby monitoring wells during the step-drawdown test to allow for a modification of the observation well network configuration. Pumping rates will be relatively low and all observation wells are within 100 feet of the pumping well.

One additional observation well (designated "j" on Figure 2-4) has been installed in a lower zone in the Burlington-Keokuk Formation at the PW-2 location. This well is placed approximately 40 feet north of the pumping well, equidistant from the shallow observation hole lines in order to prevent grout migration between wells. It is screened from 40 to 50 feet below the bottom of the pumping well. This well is double-cased and grouted to a depth below the weathered, fractured, upper aquifer, as defined by an analysis of core borings and video surveys in order to prevent transport of contaminants to lower zones during drilling operations and to avoid providing new, artificial vertical channels in the formation. Drawdown measurements in this well will allow for a determination of the degree of hydraulic connection between shallow and deeper zones in the Burlington-Keokuk Formation.

During the pumping tests, water levels will also be measured in monitoring wells within a radius of approximately 500 feet from the pumping well in order to observe any effects of pumping at greater distances.

The pumping tests will be 10 days (240 hours) in duration to allow for observation of delayed-yield effects, determination of specific yield, and observation of other effects of long-term pumping. Recovery measurements will continue until full recovery, or for a minimum of 24 hours under any circumstances. The duration of any individual pumping test may be modified by the project hydrogeologist as the test proceeds, based on drawdowns observed and determination of whether sufficient data has been collected. Water pumped from wells will be collected and stored on-site in Raffinate Pit 4 until remedial action activities commence.

The pumping tests have been designed primarily to assess aquifer properties of the upper, weathered zone of the Burlington-Keokuk Formation. The aquifer properties determined from these tests will be primarily applicable in assessing horizontal contaminant migration in the upper zone. Drawdown measurements from the deeper observation well (j) will indicate the extent of hydraulic communication between shallow and deeper zones in the bedrock. This information, combined with single-well test results and groundwater sampling results, will permit an assessment of the extent and/or potential for downward migration of contaminants. If substantial vertical migration or potential migration is present, further aquifer testing of deeper zones may be necessary. Additional testing could include further pumping tests, single-well tests, and/or packer tests. The necessity for further testing, and the type, locations, and depths of testing will be determined from the results of pumping tests, single-well tests, and groundwater sampling.

Aquifer parameters obtained from pumping tests will be based on the assumption that the aquifer is an equivalent porous medium. Therefore, pumping tests and the accompanying monitoring program are not specifically designed to trace discrete fracture flow. If major vertical fractures or solution channels are encountered during drilling operations, specific analytical models may be used as both predictive and parameters-boundary evaluation tools under water-table conditions with these fractured rock systems. Tracer tests and point dilution tests may be applicable if conduit flow is indicated or suspected.

2.2.2.2 Pumping and Observation Well Installation

Drilling operations for pumping well installation have included hollow-stem auger boring and bedrock coring to provide an accurate lithologic log of the formation at each pumping test location, followed by reaming to the final diameter by air-rotary techniques. Split-spoon samples were collected at intervals of five feet during auger drilling in the unconsolidated soils. The bedrock was cored from the bedrock surface to the total depth of the well. The log was recorded by a supervising hydrogeologist.

The borehole was reamed to a final diameter of 10 inches. The well was constructed using 6-inch inside diameter (ID) Schedule 40 PVC screen and casing. Screen length is 40 feet, encompassing the entire saturated thickness penetrated by the pumping well. Screen slot size is 0.020 inch. A filter pack consisting of 6-20 mesh silica sand was emplaced through a tremie pipe to a point 2 to 4 feet above the top of the screen. A bentonite seal, a minimum of 3 feet thick, was emplaced above the filter pack, after which the annular space was grouted to the surface using a tremie pipe.

Observation wells were installed using air-rotary techniques to drill from the land surface to the total depth. The borehole diameter is 5.5 inches. Wells were constructed using 2-inch ID Schedule 40 PVC screen and casing. Screen length for the observation wells at equal depth with the pumping well is 40 feet; slot size is 0.020 inch. A filter pack was emplaced around the screen and the annular space sealed with bentonite and grouted to the surface as described above for the pumping well.

In drilling the borehole for the deep double-cased observation well, a 10-inch diameter borehole was drilled to a depth of 10 feet below the bottom of PW-2. A 6-inch ID PVC casing was placed in the borehole for the total depth. The annular space was grouted and a grout plug at least 4 feet thick was emplaced to seal the bottom of the borehole. Drilling operations continued after the grout had set for a minimum of 72 hours. The borehole was drilled to the final depth and diameter of 5.5 inches without coring. The observation well was then installed as described above. Typical construction for pumping and observation wells is illustrated on Figure 2-5.

After each pumping or observation well installation was complete and the grout had set for a minimum of 72 hours, each well was developed to produce clear, sediment-free water and to insure hydraulic communication between the well and formation for

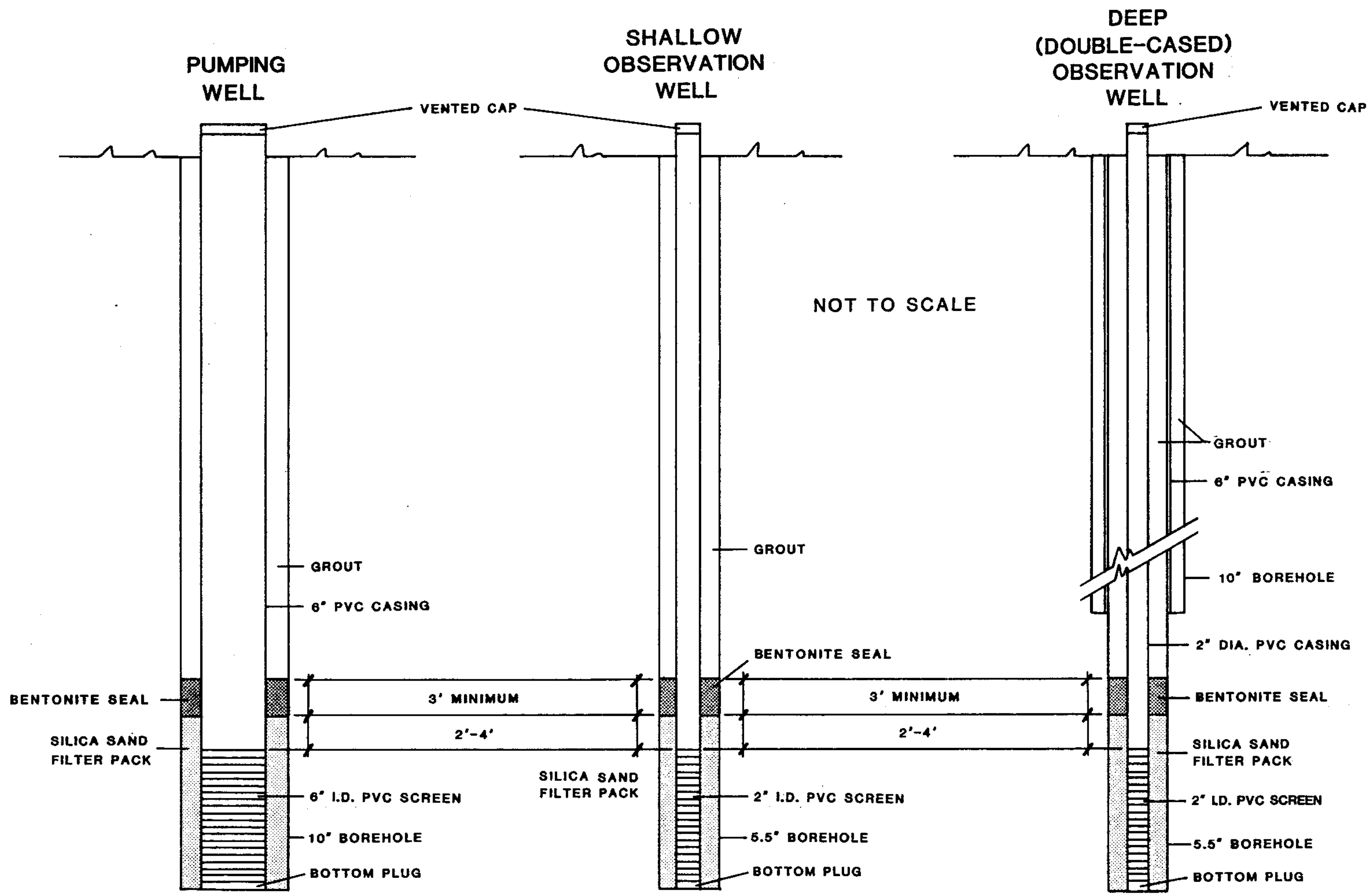


FIGURE 2-5

PUMPING AND OBSERVATION WELL CONSTRUCTION accurate drawdown and recovery measurements.

Well development is accomplished by surging and pumping. Due to the low yield of the formation, potable water was added selectively to produce more rapid, complete surging of the filter pack. This water was pumped out immediately to avoid infiltration into the formation. The 5 NTU standard was applied as a goal for completion of development and the same decontamination procedures as used for monitoring well development were followed.

2.2.2.3 Pumping Test Performance

Electric submersible pumps will be used for the pumping tests. Discharge will be held at a constant rate through the use of a gate valve. Pumping rates less than 10 gpm will be measured with a calibrated container and stop watch. Flow measurements will be recorded hourly throughout the duration of the test. During pumping the well water will be discharged to a holding tank, after which it will be pumped and transported by tank truck or pipeline to Raffinate Pit 4. Water pumped from PW-1 will be discharged through a carbon adsorption unit to remove nitroaromatics prior to discharge to Raffinate Pit 4. All raffinate pit waters will be treated prior to discharge during remedial action.

Each pumping test will begin by recording static water level measurements in the pumping well, observation wells, and nearby monitoring wells including a minimum of one well outside the radius of influence. Static water levels will be monitored for at least 48 hours prior to beginning each pumping test to ensure that steady-state conditions are present. During pumping, water levels in the pumping well will be measured and recorded using a pressure transducer and electronic data logger. Water levels in observation and monitoring wells will be measured using an electrical water level indicator or wetted tapes. Multichannel data loggers with pressure transducers in observation wells will be utilized as appropriate. Water level measurements will be recorded to the nearest 0.01 foot.

Water level measurements in the observation wells will be measured at logarithmic time intervals as pumping progresses, beginning with measurements at 1-minute intervals and increasing to 2-hour intervals after eight hours of pumping. Water levels in the pumping well will be recorded by the data logger at 1-second intervals initially, followed by a logarithmic increase in time intervals that will coincide with the observation well measurements after one hour of pumping.

After 240 hours of pumping, the pump will be shut off and recovery measurements will be collected as the aquifer recovers to the initial static water levels. Measurements will be collected during recovery at the same logarithmic time intervals used during the pumping period. Measurements will continue until all wells have recovered to the original static water levels. It is expected that the recovery period will be a minimum of 24 hours.

2.2.2.4 Data Analysis

The collected data will be analyzed to determine aquifer characteristics including hydraulic conductivity, storage parameters, anisotropy, and boundaries. Data analysis will begin by correcting the drawdown data recorded during the test for antecedent water level trends (as determined during monitoring of static water levels), partial penetration, residual drawdown (recovery data) and barometric pressure variations, and effect of precipitation events. Barometric pressure and other meteorological data are available from a National Oceanic and Atmospheric Administration (NOAA) meteorological station approximately 12 miles northeast of the WSS, the Spirit of St. Louis Airport (compiled and available upon request from National

Climatic Center, Asheville, NC) and from meteorological stations at Busch Wildlife Area Headquarters and at a utility plant approximately 10 miles to the southwest. The corrected data will be plotted for type curve analysis using methods such as those developed by Boulton and Neuman for unconfined aquifers. A qualified hydrogeologist will determine the appropriate hydrologic analyses to be performed.

In addition to calculating aquifer parameters from pumping test results, a qualitative analysis will estimate the degree to which the fractured bedrock responds to pumping as an equivalent porous medium. This will indicate the reliability of the calculated parameters. Recent publications on pumping tests in fractured bedrock will be consulted and applied as appropriate to both the quantitative and qualitative analyses.

Observation well configuration was intended to accommodate the anisotropic aquifer test analysis described by Papadopulos (1965) and Hantush and Thomas (1966). Also, Walton (1985) describes those analytical models useful in the analysis of fractured rock aquifer-test data. He presents formulae governing drawdowns with constant pumping which have been derived by Boulton and Streltsova, (1976, 1978). Recent publications pertaining to the analysis of pumping test data in fractured rock aquifers will be reviewed; and analytical models, structured to solve partial differential equations governing the flow of groundwater to wells, will be applied to evaluate data and define aquifer parameters. Neuman, at a recent (1987) NWWA symposium, described and distributed recent publications pertaining to flow in fractured rocks which may prove applicable to analysis of data obtained at the site.

The combination of quantitative and qualitative analyses will allow pumping test results to be used in conjunction with groundwater monitoring data to predict contaminant migration, and also to predict the effects of future pumping on groundwater flow patterns and contaminant concentrations.

2.3 KARST HYDROGEOLOGY

Studies of karst hydrogeology related to the WSS will be performed by the Missouri Department of Natural Resources (MDNR)--Division of Geology and Land Survey in cooperation with WSSRAP staff. MDNR efforts will focus on conduit flow from the site to local springs, both from the aquifer immediately underlying the site and from losing stream reaches draining the site. WSSRAP efforts will include sampling of springs under varying climatic conditions to determine the presence and magnitude of contaminant migration through conduit flow.

2.3.1 Flow Studies

This investigation will be divided into three phases. The most intensive efforts will occur during Phase I; Phases II and III will refine the initial findings and will aid the design of long-term monitoring and remediation programs. The conclusion of the first two phases will be followed by interim reports which will present the basic data and interpretations, including refinements of the conceptual model of the hydrogeology of the shallow bedrock aquifer system. At the conclusion of Phase III, a final report will be published as a Missouri Department of Natural Resources, Department of Geology and Land Survey (DGLS) Open File Report. This report will contain the compiled basic data with interpretations including a conceptual model of the shallow groundwater system, maps and drawings illustrating the locations of:

- Groundwater basins and divides
- Discrete and diffuse recharge areas
- Springs
- Gaining and losing stream reaches
- Conduits and voids

- The relative volume of spring flow arising from areas of discrete versus diffuse infiltration
- The relative volume of spring flow arising from conduit flow versus Darcian flow
- Recommendations for refinements and improvements in the groundwater monitoring system at WSS

2.3.1.1 Recharge and Discharge

Recharge to the shallow aquifer, which includes the karst conduit system, occurs by discrete recharge primarily from losing streams; and by diffuse recharge from general infiltration through the surficial materials. The most significant discharge from the shallow aquifer occurs through spring flow.

Field reconnaissance of all streams draining the site plus the adjacent drainage basins will be made to locate gaining stream segments, losing stream segments, springs, and seeps. Visual observations during repeated visits under differing climatic conditions will be used to identify significant springs and to classify all stream segments as either gaining or losing. More than 40 springs and seeps have already been located, of which about 20 are considered significant.

Some stream segments may not be easy to classify visually as gaining or losing. Seepage runs on these stream segments will be made to aid the classification effort. The seepage run simply consists of a series of discharge measurements made along a stream segment during a short time period to see if the flow consistently increases in the downstream direction, as would be expected for a gaining stream. If flow decreases in the downstream direction, then the stream is losing water to the subsurface and groundwater system. Seepage runs can also be used to locate groundwater discharge points where significant increases to the stream flow occur.

An effort will be made to determine what portion of the shallow aquifer discharge near the site is contributed directly by losing streams (discrete recharge) and what portion comes from infiltration of the surficial materials (diffuse recharge). This will be done by using water tracing with fluorescent dyes (see Section 2.3.1.3) to identify the springs which have groundwater drainage basins under or adjacent to the site. Gaging stations, consisting of a calibrated weir in a small dam and a water level recorder, will be established at these springs to continuously monitor their flow. Stream gaging stations will also be placed upstream of all losing stream segments that water tracing has shown are contributing to the identified springs. The difference between the total discharge at a spring and the sum of the discrete recharges (losing streams) tributary to that spring should equal the diffuse recharge component for the groundwater basin contributing to that spring.

Stream gaging stations will also be placed along the lower stretches of losing stream segments to measure flow during high runoff events when all flow is not lost to the subsurface. (During normal or low flow conditions most losing stream segments lose all of their flow to the subsurface.)

The difference between the flow entering a losing stream segment and the flow leaving it represents the maximum loss capacity of that stream segment. By using gaging stations upstream and downstream of the losing segment, recharge to the spring flow can be determined during different climatic conditions.

The diffuse recharge component of spring flow is of particular interest because it could potentially contain contaminants contributed by infiltration at the chemical plant and raffinate pit site, i.e. from contaminated groundwater plumes under the site which are connected to the karst conduit system. The discrete recharge could contain contaminants from the site but they would have to first be transported off site by surface flow to the losing stream segments. An understanding of these flow characteristics coupled with spring water quality results should suggest the probable migration pathway for contaminants.

2.3.1.2 Conduit Flow Paths

Major fractures and voids encountered during drilling for monitoring well installation will be investigated using a combination of borehole video cameras, borehole still cameras taking stereo photography, and borehole sonar mapping equipment. The results will be compared to bedrock cores. These techniques will allow better definition of the size, shape, orientation, and extent of voids and fractures.

Up to four boreholes with major voids or fractures will be used for conducting water tracing tests. Fluorescent dyes will be injected into the boreholes and significant down-gradient springs will be monitored for dye resurgence. Water tracing techniques are discussed further in the following subsection.

Spontaneous potential (SP), a geophysical technique, will be used in an attempt to locate shallow karst groundwater conduits which contain flowing water. The flowing water in the subsurface conduit creates an electrical charge surrounding the conduit. This in turn sets up a voltage potential in the ground. A digital voltmeter connected to electrodes placed in the ground is used to measure the natural voltage potential in the subsurface. A conduit containing flowing water is associated with high negative voltage readings, which are usually measured in millivolts. A square, rectangular, or concentrically circular array of electrodes is driven in the ground along with one reference electrode. The voltmeter is connected successively between the reference electrode and each electrode in the array. If a conduit with flowing water exists, it is located beneath or near the array electrodes with the most negative readings. On a map of the electrode array, a line connecting the electrodes with the most negative readings would indicated the approximate course of the conduit.

This technique will be applied to Burgermeister Spring and its subsurface tributaries. If the conduit supplying Burgermeister Spring can be successfully located, SP surveys will trace conduits upstream toward the chemical plant and raffinate pits. This effort is directed toward determining the relative contribution to flow at Burgermeister Spring from on-site and off-site sources.

As part of the geophysical/geotechnical program, geophysical surveys are planned to: 1) define depth to bedrock, 2) locate, if possible, karstic features, 3) delineate perched water zones, and 4) augment geotechnical, geological, and hydrogeological data gathered from the soils and groundwater monitoring drilling program. Data from these surveys will be evaluated and used to identify anomalies and, therefore, possible locations for additional monitoring wells. Details of geophysical, geotechnical, and soils investigation programs are presented in individual sampling plans.

Angled boreholes will be drilled under the geotechnical investigation program. Cores and logs obtained from this operation will be evaluated under the hydrogeologic plan.

2.3.1.3 Water Tracing

Water tracing using fluorescent dyes will be conducted from losing streams and from boreholes. These tracer tests will confirm, expand, and refine the understanding of the conduit flow regime developed in previous studies. Two sets of water traces are anticipated for Phase I; traces from surface locations (losing streams), and traces from subsurface locations (boreholes). The results of Phase I tests will be reported in an interim report by the MDNR and incorporated into WSSRAP RI/FS documentation. Additional water tracing tests during Phase II and Phase III will involve injection and possibly monitoring points not used for previous water tracing tests and will repeat previous traces under different climatic conditions.

Water tracing is performed by injecting fluorescent dye into the groundwater system via losing streams (where surface water streams discharge water to the subsurface) or direct injection into boreholes. Down-gradient springs or gaining stream segments are then monitored to see if the dye is present in these groundwater resurgences. Normally the groundwater discharge is sampled by anchoring packets of activated coconut charcoal in springs or in the flow of gaining stream segments. The charcoal packets, usually referred to as "bugs," are made by folding a 6-inch by 6-inch piece of nylon window screening in half and stapling the three cut edges. About 2 cubic inches of charcoal is placed inside the packet before the last edge is stapled closed. Dye is absorbed onto the charcoal as the dye-containing water flows through the bug. This sampling technique is qualitative but relatively inexpensive. A large number of locations can be continuously sampled while unattended. Bugs are periodically picked up for analysis and replaced by new ones to continue the sampling.

An alternative sampling technique is to use an automatic water sampler to take raw water samples at specified intervals. This technique allows quantitative testing to be done and more precise time of travel determinations to be made. This technique will be used at loctions where travel times are of particular interest.

Analysis for the presence of dye is done with a synchronous scanning spectrofluorometer. In the case where raw water samples are available, the raw water itself is analyzed. When charcoal bugs have been used, the dye is elutriated from the charcoal using a solution of 5% ammonium hydroxide and 95% ethyl alcohol. The elutriant is then analyzed using the spectrofluorometer.

The synchronous scanning spectrofluorometer shines an excitation light beam through a sample. When a fluorescent material is present and excited by light of the proper wavelength, the material will emit light at a longer wavelength. The wavelength and intensity of emitted light is measured by a light detection system within the spectrofluorometer. The wavelength of both the excitation light and the light being measured by the detection system (the emitted light) are varied simultaneously (synchronously scanned) over a range which includes the known characteristic excitation and emission wavelength(s) of the fluorescent material being investigated. For each sample the emission wavelength and intensity data are recorded and plotted as emission spectra. Peaks in the emission spectra can be correlated to the known wavelength peak(s) for individual dyes. The peak intensity can be correlated with the dye concentration.

The spectrofluorometer results can identify a specific dye type or types in the sample. In the case of raw water samples it can also give a quantitative concentration. In the case of charcoal bug elutriant samples, the intensity of the peak only yields a qualitative estimate of the dye concentration emerging from a spring because of variables associated with adsorption and release of dye from the charcoal and the potentially changing concentration of dye in the spring water during the sampling interval.

Before dye is injected, background samples are collected from all monitoring points and spectrofluorometric analysis is completed to record background fluorescent spectra. Dye is then injected only if the background spectra indicate there is nothing in the water that would interfere with detection of the dye to be injected. After dye has been injected and detected at one or more springs, monitoring and sampling is continued to verify that the dye pulse is decaying with time. After the groundwater system is purged of the dye or flushed and diluted to a low concentration, another injection of the same dye at a different location may be made. Experience with conducting water traces in the Weldon Spring area has shown that it usually takes about 4 months for a dye to be flushed out of the karst spring systems.

The dye type issuing from a spring can be analytically verified. However, the water tracing and sampling technique normally used provides only a qualitative result because the relative concentration is normally all that is determined. Sample chain of custody is not an issue because all sampling and testing is done in-house by the same MDNR technician or, on occasion, by another technician working with him. No special preservation of the charcoal bug is needed other than sealing each labeled bug in a separate plastic bag. Raw water samples require no preservation techniques other than keeping them protected from sunlight because the fluorescent dyes photodecay in sunlight. The plastic water sampler housing and the locking steel antitheft and antivandalism cabinet for the water sampler provide the necessary protection from sunlight. Normally, blank samples and duplicate samples are not taken. Charcoal bugs from springs outside the groundwater basin being tested serve the same purpose as a blank sample.

Standard concentrations of dye are periodically tested to calibrate the spectrofluorometer. In order to minimize the potential for contamination of the charcoal bugs with dye, the dye is always handled and injected by someone other than the technician who collects and analyzes the bugs. The dye is always sealed in a plastic bag and placed inside a second container during transportation to the injection site in order to minimize the potential for contamination of the vehicle and subsequent contamination of the bugs. At the state office building, dye is stored in a locked closet well away from the laboratory where sample preparation and spectrofluorometric analysis is done. Signs are posted on the laboratory door that indicate that no raw dye is to be taken into the laboratory.

The fluorescent dyes that will be used most extensively are Fluorescein and Rhodamine WT. Each has an approximate detection limit of 50 parts per trillion (ppt) using the spectrofluorometer and peak emission wavelengths of approximately 512 and 572 nanometers (nm) respectively. Other fluorescent dyes that will be used to a lesser extent are Tinopal CBS-X and Pyranine Impurity. These dyes have approximate detection limits of 100 and 500 ppt respectively and peak emission wavelengths of 427 nm for Tinopal and two peaks of 381 and 400 nm for Pyranine Impurity.

Because of the limited number of dyes available, the relatively long time required to flush a dye from the karst spring system, and the short window of availability (a few hours) for dyeing a monitoring well borehole before the well is constructed, not all boreholes can be dyed. Of the 33 new monitoring well boreholes, probably only four can be dyed. Therefore, a system for selecting the boreholes to be dyed has been established. The selection procedure identifies boreholes which have a high potential for open connection(s) to the karst conduits and therefore rapid movement of dye and water away from the borehole, into the karst conduits, and then to a local spring or springs. Boreholes with high potential are dyed on a first found, first dyed basis until all four dyes have been used. Subsequent boreholes with high potential will not be dyed unless additional acceptable dyes can be identified or the dye from earlier tests have been flushed from the groundwater system.

Selecting boreholes with a high potential for open connection(s) to the karst conduits is based on a review of drilling logs, examination of rock cores, and a downhole video camera examination of the borehole. The drilling logs and core are examined to locate potentially permeable zones which may be indicated by poor or no core recovery, lost circulation of drilling fluid, and fractured or solutioned rock. The video camera is then used to examine the in-situ condition of the bedrock, especially in the zones of poor or no recovery.

Presence of solution openings, highly fractured zones, and zones of groundwater inflow to the borehole are features that indicate that a borehole has a high potential for connection(s) to the karst conduits. These boreholes are then injected with dye and the dye is flushed out of the borehole, into the surrounding bedrock, and into the assumed nearby karst conduits by a follow-up injection of one to several thousand gallons of water. In some cases water may be injected before the decision is made to inject dye. In these cases, the water is used to test the ability of the borehole to accept and distribute water to the surrounding bedrock, thereby providing further information about the potential for conducting a successful tracer test.

Dye detector packets (charcoal bugs) have been placed in the perennial springs and some of the more significant wet weather springs in all the drainage basins surrounding the site. In addition, in some basins where significant springs do not exist or are located in places that are hard to monitor, dye detectors have been placed in gaining stream segments. These locations and the rationale for monitoring them are given in Table A (in Appendix) and are shown on Figure 2-6.

2.3.2 Spring and Seep Sampling

During the summer and fall of 1987, a complete reconnaissance survey of the area surrounding the WSS was performed to locate springs and seeps which are potentially affected by the WSS. This survey was performed by MDNR and WSSRAP geologists.

2.3.2.1 Sampling Locations

A total of 30 springs and seeps were identified and located on USGS 7.5-minute topographic maps. Locations of known springs and seeps and drainage divides are shown on Figure 1-22. The numbering system operates as described below.

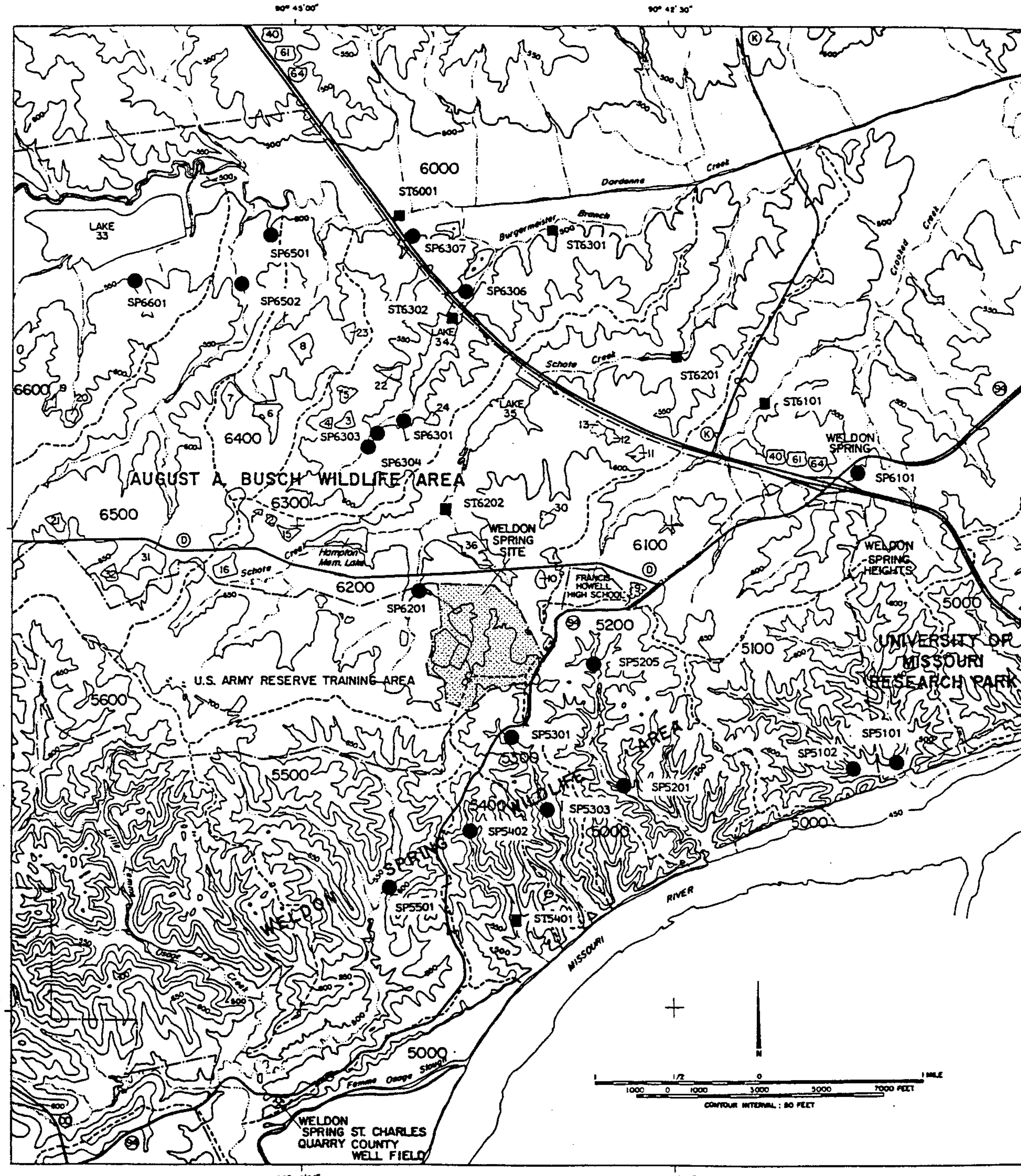


FIGURE 2-6

WATER TRACING SAMPLE LOCATIONS

Due to the uncertainty associated with the detection of contaminants and unpredictable intermittent flows at each spring, a flexible numbering system has been developed. This has been accomplished by subdividing the area-of-concern, covering over 30 square miles, into logical, discrete units. The units are defined by the surface drainage divides.

- The numbering system is in accordance with the existing WSSRAP Environmental Numbering System S.O.P.
- The prefix "SP-" denotes that the number refers to a spring or seep.
- The site and surrounding area-of-concern drain to both the Missouri and Mississippi rivers. The Missouri River drainage area is numbered along the 5000 series; the Mississippi River drainage area is numbered along the 6000 series (Figure 1-22).
- Within each thousand series, the major drainages are numbered as a hundred series from east to west as shown on Figure 1-22.
- Finally, within each drainageway, springs are numbered lowest in the series (from 1 to 99) according to permanence and volume of flow. For example, Spring Number SP-5201 represents Missouri River drainage Number 2, spring Number 1.
- Those features of concern which do not lie within one of the numbered drainages are to be placed in the zero hundred series for the appropriate thousand series. Individual spring numbers will be assigned in the chronological order of discovery of that feature.

Perennial springs are numbered first by rough estimate of greatest flow volume, the lowest number corresponding to the highest flow in each drainageway. The seeps and wet-weather springs are then numbered in order of relative flow volume. This approach will reduce the number of "holes" which can be expected to develop in the numbering sequence due to infrequent wet-weather flow or misidentification of wet-weather features. Additional springs or seeps which may be discovered at a later date in any given drainage will be numbered in chronological order of discovery.

2.3.2.2 Spring and Seep Sampling Strategy

The strategy for sampling springs and seeps to determine the volume of contaminants discharged by way of conduit flow is a dynamic program. Sampling points, frequency, and analytical parameters will be adjusted as each round of spring sampling results is interpreted.

The Phase I Spring and Seep Assessment has been undertaken to provide an initial assessment of water quality of springs and seeps. This assessment will consist of two rounds of sampling of all identified springs and seeps. One round will occur under low-flow conditions following approximately one week of no significant precipitation or snowmelt; the other round will consist of samples collected under high-flow conditions during or immediately after a significant precipitation event.

Phase I Spring and Seep samples will be analyzed for the parameters listed on Table 2-4.

The high-flow sampling was performed on December 8 and 9, 1987, following more than 24 hours of continuous rainfall. Samples were collected from 27 springs. Samples were not collected from seeps with insufficient flow or springs emerging in streambeds which were obscured by surface flow.

Low-flow sampling was performed between February 24 and 26, 1988. A Phase I Spring and Seep Assessment report presenting and interpreting analytical results from both the high-flow and

TABLE 2-4

ANALYTICAL PARAMETERS FOR SPRING AND SEEP SAMPLES

Uranium (natural)	Fluoride
Radium 226	Hardness
Radium 228	Total Dissolved Solids
Thorium 230	Total Organic Carbon
Thorium 232	*CLP Metals
Gross Alpha	Lithium
Gross Beta	*CLP Organics
Nitrate	**USATHAMA Nitroaromatics
Sulfate	Pesticides
Chloride	

* Contract Laboratory Program

** United States Army Toxic and Hazardous Material Agency low-flow sampling events is presently in draft form.

Results of the Phase I Spring and Seep Assessment and results of previous dye traces will be used to design a continuing sampling strategy. Selected springs with elevated levels of contaminants may be included in routine quarterly monitoring under the WSSRAP Environmental Monitoring Program (EMP). (Burgermeister Spring and the adjacent wet-weather spring are currently included in the EMP.) Further spring and seep sampling will include sampling during and following storm events as well as routine sampling to accurately characterize the range and peak concentrations of contaminants discharged at springs (Quinlan and Alexander, 1987). Sampling strategy will be re-evaluated as results of new dye traces are received.

2.4 OVERBURDEN HYDROGEOLOGY

Studies of overburden hydrogeology will be performed to determine whether contaminants present in an unsaturated flow regime or in perched or mounded zones represent a continuing source for groundwater contamination. These studies will focus on determining the presence of contaminants and of unsaturated flow conditions which could transport contaminants to the groundwater. The results will be used for computer modeling of unsaturated flow, groundwater flow, and contaminant transport.

The materials comprising the overburden at the site include the upper 10-20 feet of weathered limestone bedrock, a well developed layer of residuum in most areas, basal till, clay till, silty clay, loess, and topsoil/fill. Total overburden thickness ranges from 20 feet to 50 feet. The overburden is generally unsaturated. A detailed description of the overburden material is presented in Section 1.2.4.1

2.4.1 Unsaturated Flow Conditions

The movement of water through unsaturated soils is a function of gravity and tension (or suction) forces. Tension forces are referred to as the tension head or suction head, and are expressed in terms of negative atmospheric pressure.

To estimate the rate of flow through unsaturated soils, the modified form of Darcy's equation may be used:

$$\mathbf{V = -K(\Theta)\ H}$$

Where V is the flux, K is the hydraulic conductivity at a specific moisture content Θ (unsaturated hydraulic conductivity is a function of moisture content), and H is the hydraulic gradient vector, which is the sum of the soil-water pressure head and the gravity (elevation) head expressed as a vector. Moisture content may be used as an estimate of the pore space available for flow. Thus, the above equation is divided by the moisture content to obtain an estimate of the average linear velocity ($\mathbf{v}$) through a particular soil. The equation then becomes:

$$\mathbf{v} = \frac{\mathbf{-K(\Theta)\ H}}{\mathbf{\Theta}}$$

In order to use this equation to estimate flow rate, the unsaturated hydraulic conductivity, moisture content, and the hydraulic gradient must be determined by field and laboratory measurements.

Previous efforts to characterize the saturated hydraulic conductivity of the vadose zone were performed by Bechtel National, Inc. (1987). Section 1.2.6 presents a summary of these tests on the vadose zone. Packer tests in the unsaturated bedrock zones indicate variations in saturated hydraulic conductivity of up to four orders of magnitude ranging from 6.8 x

10^{-6} to 8.5×10^{-3} cm/s. The results indicate that the bedrock is of variable hydraulic conductivity in the horizontal plane and generally becomes less permeable with depth, due to decreased weathering and associated solution activity (BNI, July 1987). Overburden characteristics at the WSSRAP were also evaluated and discussed in the BNI, November 1984, and July 1987 reports. The upper few feet of overburden (mostly topsoil) are poorly drained. The materials underlying the topsoil are unsaturated. Disturbed and undisturbed samples of the major overburden units were submitted to a laboratory for soil testing. The saturated hydraulic conductivities and moisture content of both dike fill and foundation materials were determined. The saturated hydraulic conductivity values are generally low and range from 1.6×10^{-9} cm/s (4.5×10^{-6} ft/day) to 3×10^{-6} cm/s (8.5×10^{-3} ft/day). Saturated hydraulic conductivity values for the silty clays and clayey silts are the highest measured. The geometric mean of the test results is 1.3×10^{-7} cm/s (3.7×10^{-4} ft/day). The field moisture content of the samples range from 15% to 30%. This is approximately 90-100% saturated moisture content. Test results for the clay materials obtained from a depth of about 3 m (10 ft) indicate a saturated hydraulic conductivity range from 1.7×10^{-8} cm/s ($4.82 \text{ X } 10^{-5}$ ft/day) to $6.4 \text{ X } 10^{-9}$ cm/s (1.81×10^{-5} ft/day).

Comparison of grain size distributions of the four units indicates the basal till has the highest gravel content, the clay till has the highest sand and clay content, and the loess has the highest silt content (Table 1-2). The clay till exhibited the highest cation exchange capacity, followed by the Ferrelview Formation and lastly, the basal till (BNI, July 1987).

Relevant soil parameters measured by the laboratory for the Ferrelview Formation, the clay till unit, and the basal till unit are discussed in Section 1.2.4.1. Table 1-2 presents a summary of the overburden test results. These data indicate that the

Ferrelview Formation has the highest saturation, specific retention, and activity, and the lowest specific yield (BNI, 1987).

2.4.1.1 Unsaturated Zone Storage Potential

The physical properties of the vadose zone that influence water storage potential include: (1) thickness, (2) porosity, (3) bulk density, (4) water content, (5) soil-water characteristics, (6) field capacity (specific retention), (7) specific yield, and (8) fillable porosity (Everett, 1984). The evaluation of these parameters is necessary to properly assess the hydraulic properties of the unsaturated zone in order to predict contaminant migration.

- Thickness

  A determination of the thickness of the vadose zone will be based on borehole information and current water level measurements from existing and proposed monitoring wells. In areas underlain by perched groundwater, the depth to the perched water table will be used as the depth of the vadose zone.

- Bulk Density and Porosity

  Bulk density values are required for the estimate of total water storage in the vadose zone.

  Bulk density and porosity results from previous studies by BNI will be combined with new data from the geotechnical investigation efforts to produce a body of data suitable for unsaturated flow calculations and model calibration.

o Water Content

The total porosity (n) of the unsaturated zone materials corresponds to the upper limit for water storage in the unsaturated zone. However, for $\theta < n$, the available porosity for liquid flow is a function of the water content. Field techniques for determining water content of the unsaturated zone will utilize tensiometers and neutron moisture probes. A more detailed discussion of the use and field implementation of these instruments is presented in Section 2.4.1.3.

o Soil-Water Characteristics

The relationship between soil-water tension and water content is referred to as the soil-water characteristic curve. As a soil drains, a range of soil-water content values are possible, depending on the various forces acting on the soil-water system. These forces include matric forces, osmotic forces, and gravity. Usually, the matric force is dominant. When expressed on a unit volume basis, the energy associated with these forces is termed soil-water pressure (Everett, 1984).

Tensiometers will be used to measure the soil suction negative pressure head in the field at a specific point in the soil column. Tensiometers may be used only when soil-water negative pressures are greater than -0.8 bar (i.e. between -0.7 and 0.0 bar) (Everett, 1984). They must also be correlated to measurements of soil moisture. This can be done by reference to an existing soil-moisture characteristic curve. If such a curve is not available, it must be developed from additional laboratory testing. Field sampling and measurement may also be used to supplement laboratory testing. The soil may be sampled at the time of tensiometer installation and the moisture content of this sample compared to the initial tensiometer reading. However, this will supply only one point on the curve relating soil moisture and soil suction.

In the case of the WSS, a soil-moisture characteristic curve is not available. A combination of field and laboratory methods will be used to develop a soil-characteristic curve for the soils at the WSS which relates moisture content and soil suction. Laboratory testing using pressure plate analysis or other methods must be used to determine additional points along the curve relating soil moisture and soil suction. Once this relationship has been established, the soil characteristic curve can be used to determine the soil moisture based on future tensiometer readings.

- Field capacity (specific retention)

Field capacity is related to the volume of water that a unit volume of soil will retain against the force of gravity. Approximate values of field capacity (on a mass/mass basis) vary from 4% in heavy clays up to 100% or more in organic soils. In terms of matric potentials, values for sands range from 0.1 to 0.15 bar at field capacity. For medium- to fine-textured soils, the corresponding range is 0.3 to 0.5 bar (Everett, 1984).

- Specific yield

Estimates of the specific yield values for areas near the water table and perched areas of saturation in the vadose zone will be obtained from water content profiles as determined from neutron moisture logs. The neutron moisture data will be used to determine the volume of water drained during the decline in the water table.

- o Fillable porosity

  The fillable porosity is the volume of water that an unconfined aquifer stores during a unit rise in the water table per unit surface area. Neutron moisture logs may be used to estimate the fillable porosity of sediments near the water table.

2.4.1.2 Unsaturated Flow Potential

The vadose zone flow regime at this site may be characterized as two flow regimes, Darcian (capillary) flow and macropore flow. Darcian flow describes a uniform, slowly advancing wetting front, while macropore flow is the relatively rapid transmission of free water through large, continuous pores or channels (such as root channels, desiccation cracks, or fractures). The principal unsaturated flow parameters that need to be evaluated at this site are: 1) infiltration, 2) the amount of water moving into the lower vadose zone, 3) the direction of unsaturated water movement, 4) hydraulic gradients, 5) the unsaturated hydraulic conductivities, and 6) flow rates (flux).

The method to be used at the site to estimate infiltration is the instantaneous rate method which involves measuring seepage loss over a short time interval at an excavated impoundment.

The determination of direction of water movement and hydraulic gradient in the unconsolidated material will rely primarily on neutron probe measurements. Measurements will be taken by inserting the neutron probe into the infiltration tubes and recording the neutron response to moisture content of the soils at various depths. Using this method, the neutron source and neutron counter are contained in the same unit and high energy neutrons, which have about the same mass as hydrogen, are emitted from the source into the soil. As these neutrons collide with hydrogen they lose part of their energy and are counted as they are scattered back toward the probe. The number of counts that are recorded in a specified time can be related to the hydrogen content of the soil, which is primarily the soil moisture content.

A soil characteristic curve is then used to estimate the soil suction (negative pressure head). One tensiometer nest will also be used as a correlation of field measurements. Tensiometers are used to measure the soil suction or negative pressure head at a specific point in the soil column. A soil characteristic curve is then used to estimate the moisture content of the soil (see 2.4.1).

In order to characterize the direction of unsaturated water movement in the vadose zone, an array of three neutron probe infiltration tubes will be installed at each selected location to determine variations in soil moisture with respect to depth. A nest of three tensiometers will be installed at one infiltration tube location with individual cups terminating at varying depths. This will be located as close as possible to the location of the infiltration tube. Disturbance of soils will be minimized. Correlation between the neutron soil moisture readings and the tensiometer soil suction can be made at this location and the results used at other points in the vadose zone monitoring network.

Hydraulic gradients will be used to estimate flux in the vadose zone. The hydraulic gradients in the vadose zone will be derived from tensiometer and neutron probe data. Soil-characteristic curves derived from lab and field data will be used to relate negative pressure measurements (from tensiometers) or the moisture content measurements (from neutron probes) to water content and unsaturated hydraulic conductivity (Everett et al, 1984).

2.4.1.3 Site Monitoring

The vadose zone monitoring network is designed to investigate the vertical and horizontal extent of contamination and to provide insight into the potential for movement of fluids in the vadose zone. Monitoring of the vadose zone will involve a combination of field and laboratory techniques. Neutron probes will be the primary technique used to measure moisture content at most locations in the vadose zone. Neutron moisture logging will provide detailed information on the relationship between moisture content and negative pressure. Advantages of the neutron probe are its abilities to obtain soil moisture measurements over a wider range of soil moisture content than tensiometers and to allow measurements of a continuous soil moisture profile (with depth). A tensiometer nest will be used to correlate the in-situ soil suction or pressure head with the soil moisture measurements (determined by neutron probe measurement) at one monitoring point in the vadose zone. The data derived from the tensiometers and neutron probes will facilitate the determination of hydraulic gradients and, indirectly, fluid movement (flux) in the vadose zone.

At the time of installation of the in-situ devices, the moisture content of the soil from the neutron probe access wells and the tensiometer cup locations will be determined from undisturbed samples (see Section 2.4.1.5 for sampling technique). These data will be used to supplement laboratory data to create a soil-water characteristic curve which can then be used to estimate the moisture content of the soil and allow subsequent neutron probe and tensiometer readings to be used to estimate flux.

2.4.1.4 Location and Rationale

This section presents the proposed locations and rationale for vadose zone monitoring points and for the field implementation of the monitoring program. The goals of the vadose zone monitoring program are to:

(1) Investigate vadose zone processes in and near suspected source areas for continuing groundwater contamination.

(2) Provide information for the evaluation of contaminant migration in the vadose zone.

(3) Provide representative data on vadose zone parameters throughout the site for input to computer models.

(4) Provide long-term monitoring data to allow for the estimation of seasonal variation of potential paths of migration.

(5) Evaluate the effectiveness of the soil zone in terms of the degradation, transformation, or immobilization of contaminants.

Proposed locations for the neutron probe monitoring network are presented on Figure 2-7. The locations were selected to determine unsaturated flow conditions in areas where contaminants have been detected in the groundwater and could potentially migrate off-site, and also at a location adjacent to a possible site for the proposed disposal facility. In general, the locations of the neutron probe arrays correspond to the pumping and observation well locations. As shown in the detailed enlargement on Figure 2-7, each location will contain an array of three neutron probe infiltration tubes. The tubes will be located 25 feet apart. These three points describe an equilateral triangle. Array 1 (IT-1) is located north of the apparent groundwater divide in the area where relatively high concentrations of nitroaromatic compounds were detected in groundwater samples. Array 2 (IT-2) is located adjacent to a

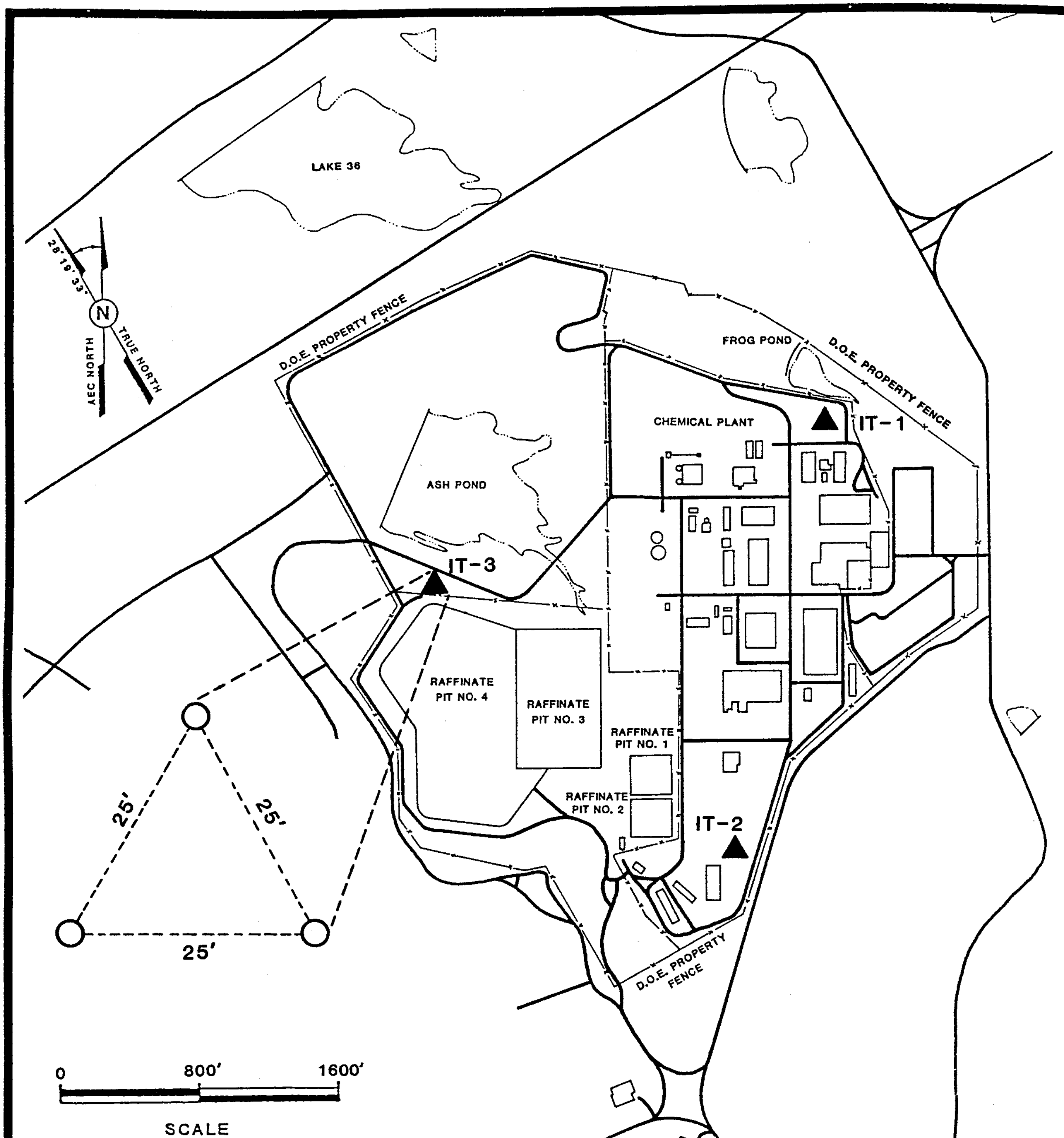


FIGURE 2-7

LOCATION OF INFILTRATION TUBE NETWORK

possible site for a proposed disposal cell area near the southern end of the site. Array 3 (IT-3) is located in the area where the highest nitrate concentrations were detected in groundwater samples from the Phase I Water Quality Assessment. At location IT-2, one array will contain a tensiometer nest containing three tensiometer cups at three different depths.

There may be some variations in correlation between the neutron probe soil moisture measurements and the tensiometer soil suction measurements. This is expected due to hysteresis effects during the wet-dry cycle in unsaturated conditions. To insure that the neutron probe is accurately reflecting field conditions, it will be calibrated at least once yearly using a standardized field installation.

Additional neutron probe monitoring tubes will be installed at each existing and proposed lysimeter location. This will allow localized in-situ soil moisture measurements so that lysimeter sampling can be optimized.

A phased approach to neutron probe monitoring tube/lysimeter installation will be used for the proposed locations. Neutron probe soil moisture measurements will be taken for approximately three months prior to lysimeter installation. Moisture profile data from these measurements will allow more precise depth location of each lysimeter.

2.4.1.5 Drilling and Installation

All drilling activities to be conducted for the installation of the tensiometer nest and neutron moisture logging infiltration tubes will be in accordance with SOPs (WSSRAP procedures manual).

Drilling operations will utilize hollow-stem augers to advance and sample boreholes. Undisturbed samples will be obtained from intervals which will, at a minimum, correspond to the horizons monitored by the tensiometers (10, 20, and 30 feet). The supervising geologist will maintain a complete log of each soil boring. Sampling intervals will be adjusted to intercept seams of differing soil type and those intervals which appear to contain abundant soil moisture. Thin-walled tube (Shelby Tube) sampling will be used to obtain undisturbed samples of the unconsolidated overburden materials.

Each infiltration tube borehole will be drilled to a depth of 30 feet. The infiltration tube is constructed by hydraulically driving a 2 3/8 inch core barrel into the soil. The core barrel is advanced 4 feet at a time after which the soil sample is removed. When the advancement of the core barrel reaches a depth of 30 feet, a 2 3/8 inch OD aluminum pipe is inserted into the hole. At ground surface bentonite is placed around the tube to prohibit water from percolating into the annular space and affecting the measurements made with the neutron probe. A secure cap with controlled access should be installed over the infiltration tube to prevent entry of debris, water or contaminants (Figure 2-8). The neutron probes will be calibrated by comparison to laboratory measurement of the moisture content of soil samples that were removed during the installation of the infiltration tube.

Tensiometer measurements are effective only in unsaturated soils where soil-water pressures are between -0.8 bar and 0.0 bar. Pressures below -0.8 bar will be correlated to soil moisture content using lab testing and neutron logging.

Tensiometers will be installed in a nest with individual cups terminating at varying depths throughout the region of interest. The tensiometer nest will consist of three tensiometers (Figure 2-9). The A1 tensiometer cup will terminate at the upper or horizon 1 level; the A2 will terminate at the middle or horizon 2 level; and A3 will terminate at the lower or horizon 3 level. These levels correspond to depth intervals of 10, 20, and 30 feet

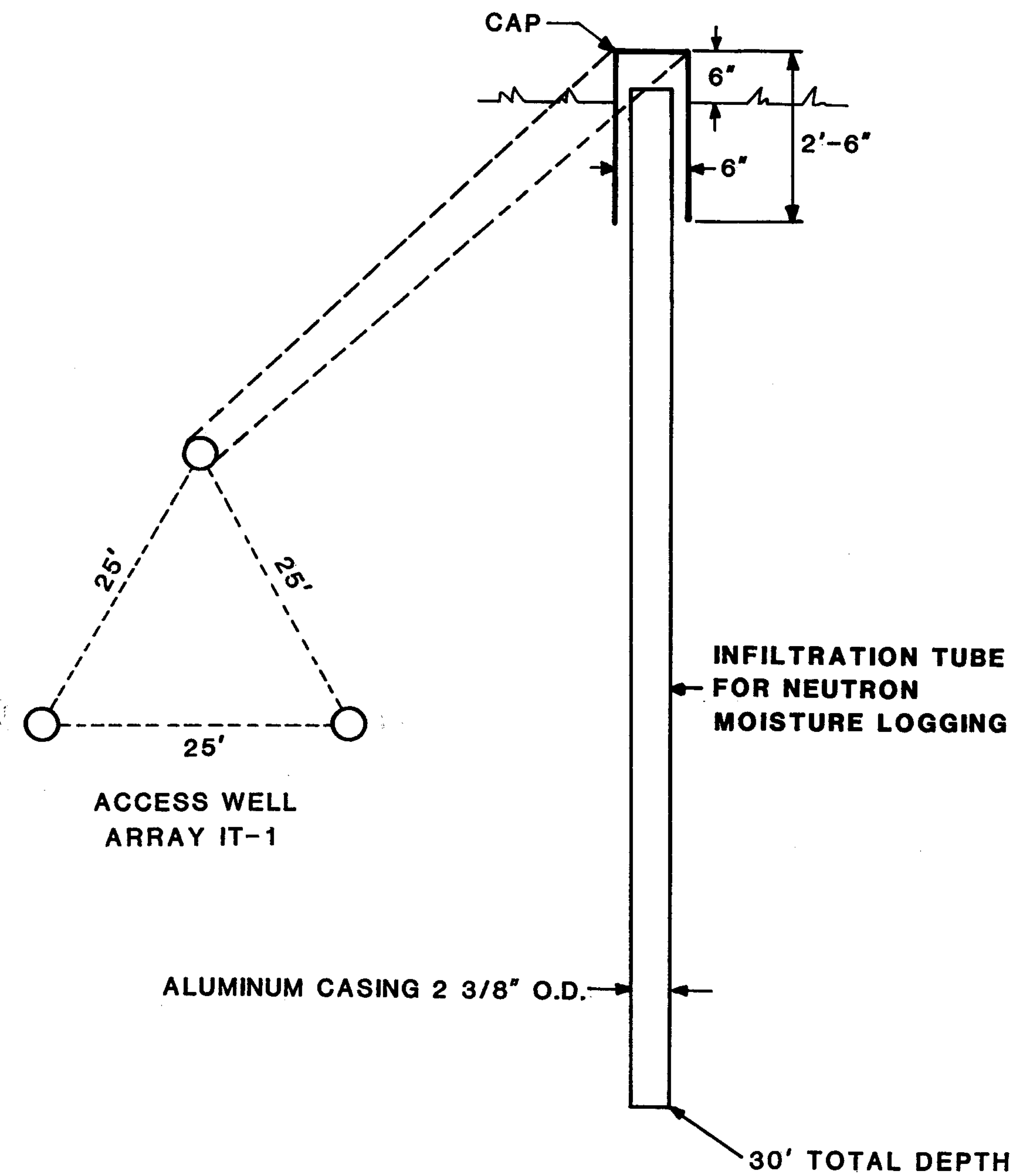


FIGURE 2-8

TYPICAL INFILTRATION TUBE DIAGRAM

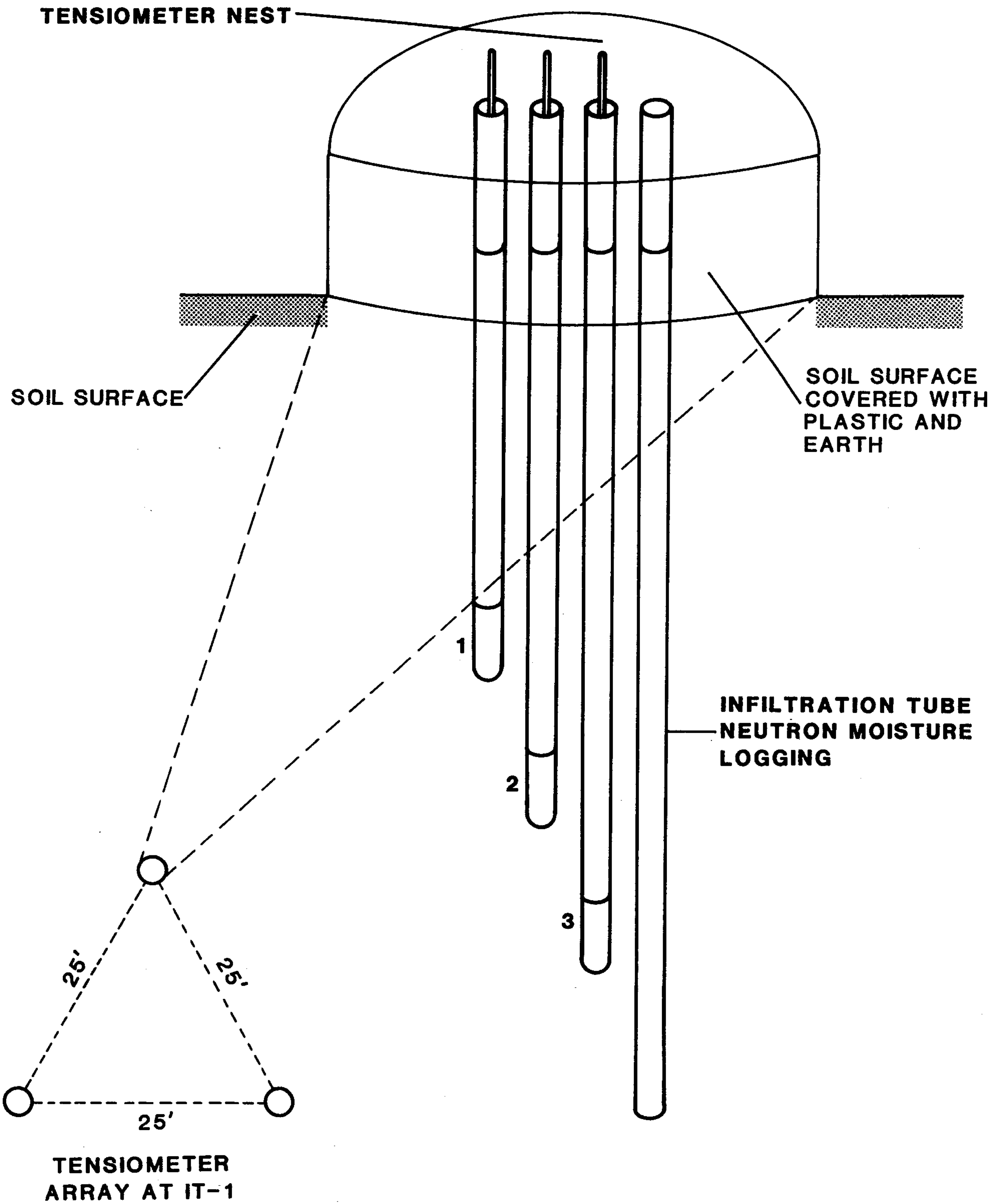


FIGURE 2-9

PROPOSED TENSIOMETER ARRAY DIAGRAM

respectively. The intervals will be adjusted, based on field observations, to intercept zones where moisture is accumulating.

The borings to complete the tensiometer nest will be spaced four feet apart (Figure 2-10). Adjustments in spacing may be necessary to accommodate actual site constraints. Care will be taken to minimize disturbance of adjacent borings when drilling the closely-spaced holes for the tensiometer nest.

Tensiometers will be immersed in water during transport to the field. Silica flour (200 mesh) will be tremmied to the bottom of the hole. The tensiometer cup will then be forced into the silica flour and the tube carefully backfilled with soil to prevent surface water leaking down the tube (Everett et al, 1984).

2.4.2 Contaminant Distribution in the Vadose Zone

Soil pore-liquid sampling will be performed to evaluate the efficiency of the soil processes that degrade wastes, and to detect the migration of hazardous constituents through unsaturated flow.

The sampling of unsaturated soil pore-liquids will utilize vacuum pressure lysimeters. Usually, vacuum lysimeters will collect liquid only at pressures above -0.8 bar, limiting the effective range of soil moisture where samples can be obtained. Soil moisture will be monitored by installing neutron probe access wells in close proximity to each lysimeter location. Figure 2-11 shows a typical single vacuum-pressure lysimeter (EPA, Oct. 1986).

2.4.2.1 Existing Lysimeters

Figure 1-18 presents the location of the existing lysimeter network installed by UNC Geotech in July 1987. Analysis of soil pore water from these lysimeters indicated elevated concentrations of nitrate, calcium, and sodium.

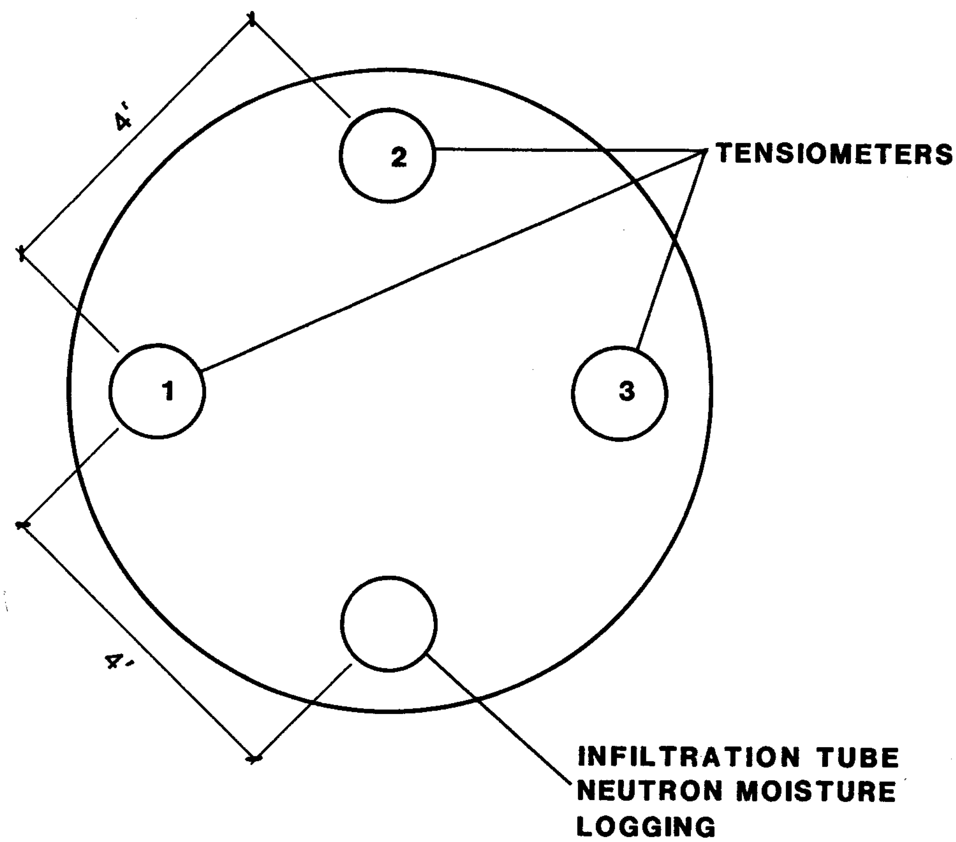


FIGURE 2-10

PROPOSED TENSIOMETER NEST DIAGRAM

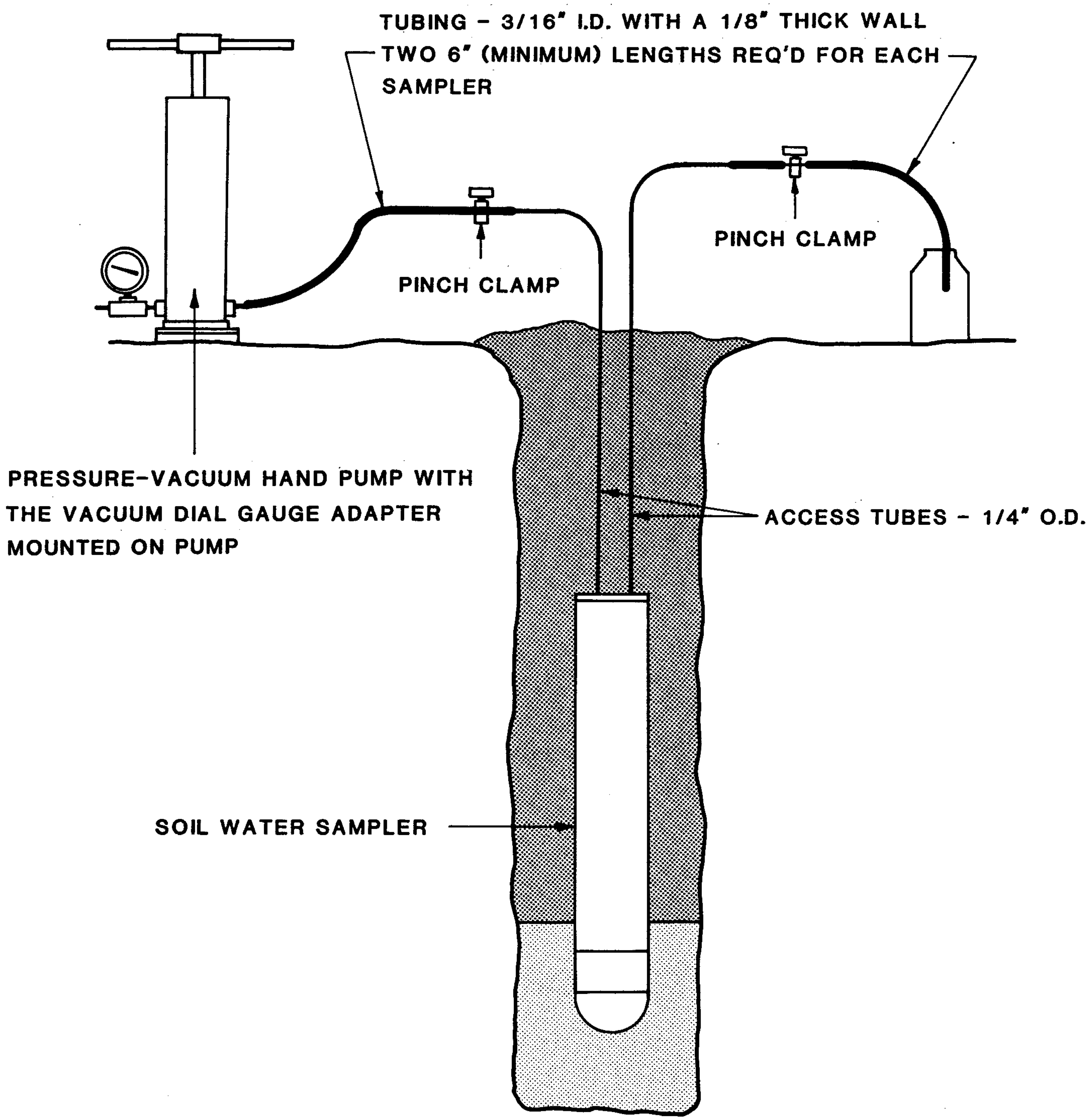


FIGURE 2-11

TYPICAL VACUUM - PRESSURE LYSIMETER

The proposed overburden monitoring program includes installation of neutron probe access wells and continued collection and analysis of samples from these existing lysimeter locations. Also additional neutron probe/lysimeter arrays will be installed and monitored at select locations to evaluate contaminant transport by unsaturated flow.

2.4.2.2 Additional Lysimeters

The location and rationale for additional multiple lysimeter installations were established by reviewing: (1) documented evidence of areas exhibiting soil and/or groundwater contamination, and (2) potential contaminant source areas.

The proposed locations for additional multiple lysimeter installations are shown in Figure 2-12. Table 2-5 lists the rationale for lysimeter placement. The intervals to be monitored at each location are listed in Table 2-6. This table also includes a lithologic description of the interval which is based on the log of the nearest boring. These intervals will be adjusted, based on field observations, in order to intercept zones where moisture is accumulating.

The characteristics of the residuum and unsaturated bedrock will be defined under the geotechnical investigation plan. Lysimeter locations presented on Figure 2-12, supplemented by existing lysimeters, represent a minimal vadose zone monitoring network. This focused operation may be expanded, if necessary, with the acquisition and analysis of data from drilling and sampling programs, including the chemical soils investigation, monitoring, geophysical/geotechnical investigation, waste characterization (e.g. raffinate pit sludge analysis) and the drilling and sampling programs delineated in this plan.

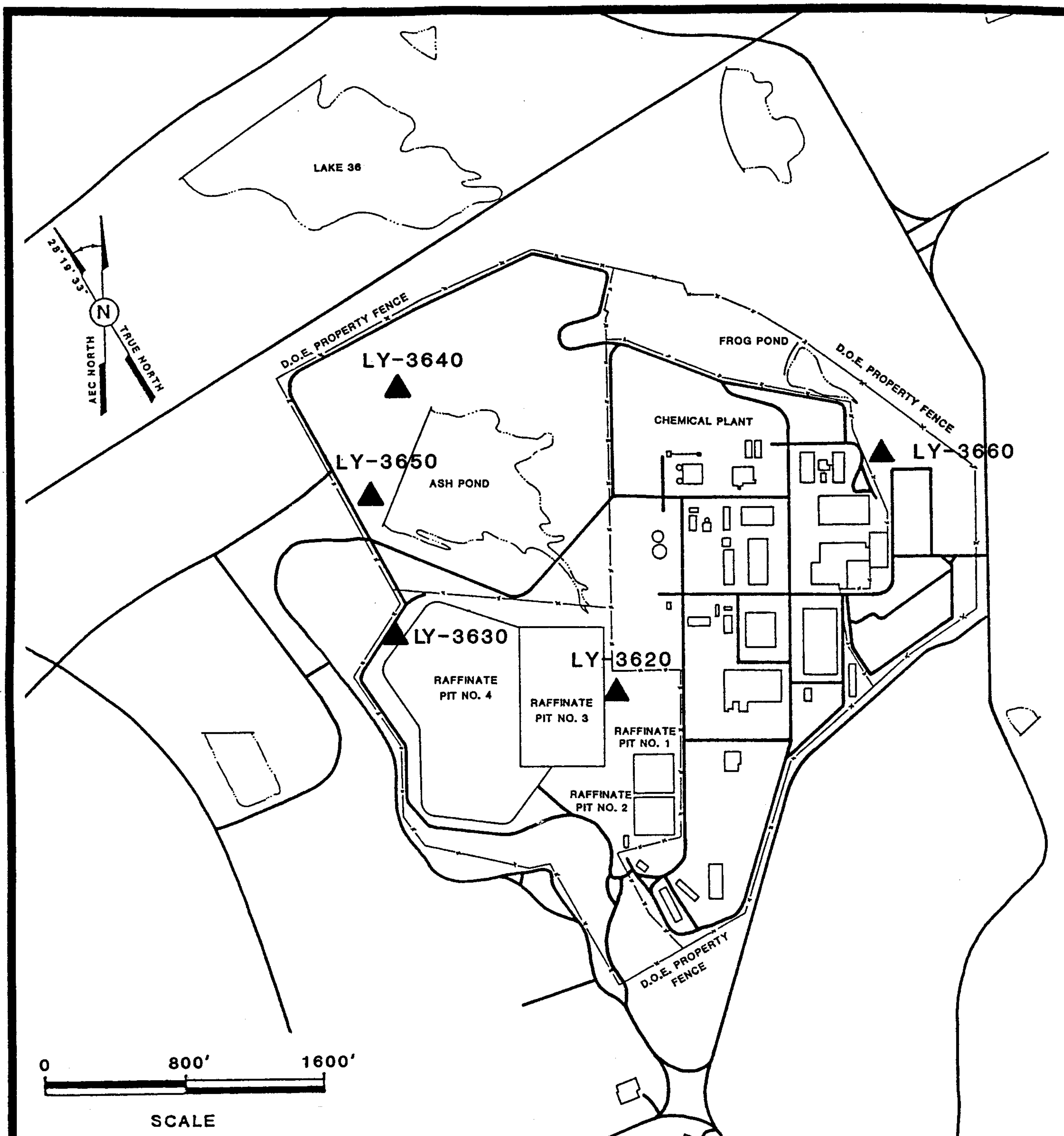


FIGURE 2-12

ADDITIONAL MULTIPLE LYSIMETER INSTALLATION LOCATIONS

TABLE 2-5

LYSIMETER PLACEMENT RATIONALE

Lysimeter Location Number	Location	Rationale
LY-3620	E. of Raffinate Pit 3	Area of dark green vegetation may indicate leakage from Raffinate Pit 3, or potential migration extending from Raffinate Pit 1.
LY-3630	N.W. of Raffinate Pit 4	Previous drilling in this area encountered very moist zones. Potential seepage from Raffinate Pit 4.
LY-3640	N.W. of Ash Pond near north dump area	Previous drilling operation in this area encountered a very sandy silt. Area delineated as ordnance demolition storage area. Also, saturated materials were encountered during BNI drilling and testing activities.
LY-3650	S.W. of Ash Pond down-stream toe of embankment.	Area of nitrate & sulfate contamination, and ordnance demolition storage area. Area also exhibiting saturated soil during BNI drilling & testing activities.
LY-3660	N. of Bldg.407, near monitoring well MW-2013	Area of 2,6 DNT contamination and area delineated as potential nitroaromatic source from TNT processing. Also area exhibiting saturated soil during BNI drilling & testing activities.

TABLE 2-6
MULTIPLE LYSIMETER INSTALLATION SUMMARY

Lysimeter Location/ Borehole	Depth Interval	Description
LY-3620		
LY-3621	10.0 - 12.0	Clay, silty, brownish-gray to med. gray, moist oxidized zones
LY-3622	18.0 - 20.0	Clay, silty, med. gray, moist, some sub-rounded fine gravel, trace very fine-grain sand, oxidized zones, pyrolusite stringers
LY-3623	23.0 - 25.0	Clay, gravelly, dark yellowish orange, moist, hard, angular chert gravel, pyrolusite lenses, trace very fine-grain sand
LY-3630		
LY-3631	10.0 - 12.0	Clay, silty, gravelly, lt. gray w/orange mottling, some angular chert fragments
LY-3632	17.0 - 19.0	Clay, silty, orange/gray, moist, some chert pebbles
LY-3633	22.0 - 24.0	Clay, silty, gravelly, dk. brown w/orange, moist, red angular chert fragments
LY-3640		
LY-3641	5.0 - 7.0	Silt, orange & greenish gray, some clay, black modules, very stiff
LY-3642	10.0 - 12.0	Clay, silty, mottled orange & gray, very stiff
LY-3643	18.0 - 20.0	Clay, silty, yellowish orange-orange & gray mottled, very stiff to hard, black manganese oxide staining common
LY-3650		
LY-3651	6.0 - 8.0	Silt, clayey, tan to light brown, some black manganese oxide staining
LY-3652	11.0 - 13.0	Clay, mottled orange-brown-gray, stiff, minor manganese oxide staining
LY-3653	18.0 - 20.0	Clay, silty, mottled orange, yellowish-brown and gray w/fine-grain sand & weathered angular chert gravel, black manganese oxide staining & fillings common
LY-3660		
LY-3661	6.5 - 8.5	Silt, clayey, mottled tan & gray, very soft
LY-3662	11.0 - 13.0	Silt, clayey, mottled, stiff, common dark reddish brown iron nodules
LY-3663	18.0 - 20.0	Clay, silty, mottled, very stiff, w/white sand sized chert fragments, occasional black manganese oxide staining and fillings mottled orange & light olive gray

*Descriptions based on nearest logged boring

2.4.2.3 Drilling and Installation

A phased approach to neutron probe infiltration tube/lysimeter installation will be used for the proposed lysimeter locations. Neutron probe soil infiltration tubes will be installed first and moisture measurements will be taken for approximately three months prior to lysimeter installation. Moisture profile data from these measurements will allow more precise depth location of each lysimeter.

All lysimeter drilling and installation activities will be conducted in accordance with the Standard Operating Procedures (SOPs) developed for borehole logging and lysimeter installation and sampling. Drilling operations will utilize hollow-stem auger techniques.

Undisturbed samples will be obtained from the intervals corresponding to the horizons or intervals to be monitored by the lysimeter. Thin-walled tubes will be used to obtain undisturbed samples of the unconsolidated overburden materials. These samples will be retained for possible future chemical analysis. The supervising geologist will maintain a complete log of each soil boring.

In general, lysimeter installation will consist of placing enough silica flour (200 mesh) into a borehole at the proper lysimeter depth interval to form a six- to twelve-inch thick layer. After lowering the sampler into the hole, additional silica flour will be added to cover the sampler to a point at least two inches above the top of the porous cup. The sampler will then be rotated into the silica flour to insure the porous cup is in good contact with the silica flour. The hole will then be backfilled with tamped native soil. A bentonite seal is required above and below each lysimeter in multiple sampler installations (Figure 2-13).

MULTIPLE INSTALLATION

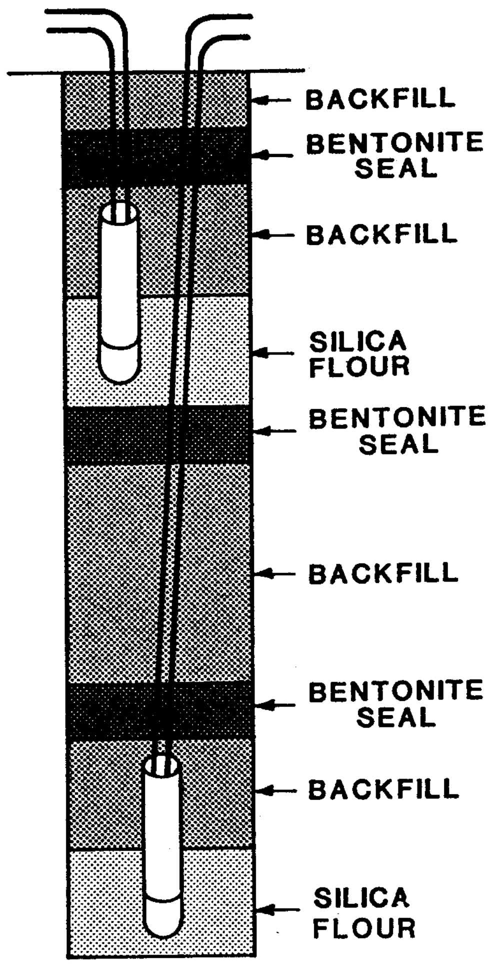


FIGURE 2-13

TYPICAL MULTIPLE LYSIMETER INSTALLATION

2.4.2.4 Soil Water Sampling

Soil water sampling will be performed in conjunction with the quarterly monitoring described in the 1987 Environmental Monitoring Program Plan. Sample collection techniques are described in detail in the WSSRAP Standard Operating Procedures. Repeated sampling over a period of time may be required to collect sufficient sample volume for a complete analysis. The order in which the constituents are analyzed may be prioritized, with analyses for contaminants of greatest concern performed first. Soil water samples will be analyzed for the parameters listed previously in Table 2-3. Analytical results will be entered into a computer data base.

2.4.3 Perched and Mounded Groundwater Zones

The geological environment at the WSS exhibits complex saturated-unsaturated conditions occurring within the vadose zone. Saturated regions within the vadose zone (perched groundwater bodies) result from the presence of a lower permeability layer in a relatively higher permeability formation, or from seepage into a low permeability, poorly drained soil. The result is the formation of discontinuous saturated lenses with unsaturated conditions existing below these lenses and above the water table.

Investigations of perched and mounded zones will focus on the immediate vicinity of the raffinate pits. Previous exploratory drilling investigations conducted at the WSS indicated areas of anomalously high groundwater elevations or perched groundwater (see Section 1.2.6).

Monitoring of perched groundwater at the WSS will be accomplished by the use of overburden monitoring wells. Discrete zones within the overburden are to be monitored.

Previously installed monitoring wells that will be retained in the network are illustrated on Figure 2-14. Overburden monitoring wells OW-3501 and OW-3502 were installed by UNC Geotech in 1987 to allow monitoring of shallow seepage from Raffinate Pits 1 and 3. OW-3503 was installed as a monitoring well in 1983 by BNI and designated B-15A, later designated MW-3005 by WSSRAP staff prior to the development of separate monitoring strategies for saturated overburden and the bedrock aquifer. OW-3504 was installed in 1980 by Lawrence Berkeley Laboratories and designated W-2, later designated MW-3018. The overburden surrounding the screened interval of this well is seasonally unsaturated. OW-3508 was installed in May 1988 incidental to other drilling activities near Raffinate Pit 3. This location will serve to monitor potential mounding from Raffinate Pit 3.

Other monitoring wells installed in the overburden during the course of previous investigations in the raffinate pits area have either remained continuously dry or have been damaged and abandoned.

Additional overburden monitoring wells will be installed in areas previously identified as exhibiting potentially perched or mounded groundwater conditions in the overburden.

2.4.3.1 Location and Rationale

The overburden monitoring network is designed to further investigate the vertical and horizontal extent of contamination in perched groundwater zones and to evaluate leakage from the raffinate pits.

The location and rationale for monitoring well installation were established by reviewing the results from previous subsurface investigations by Bechtel National, Inc. and UNC Geotech. Figure 2-15 presents the proposed overburden monitoring well

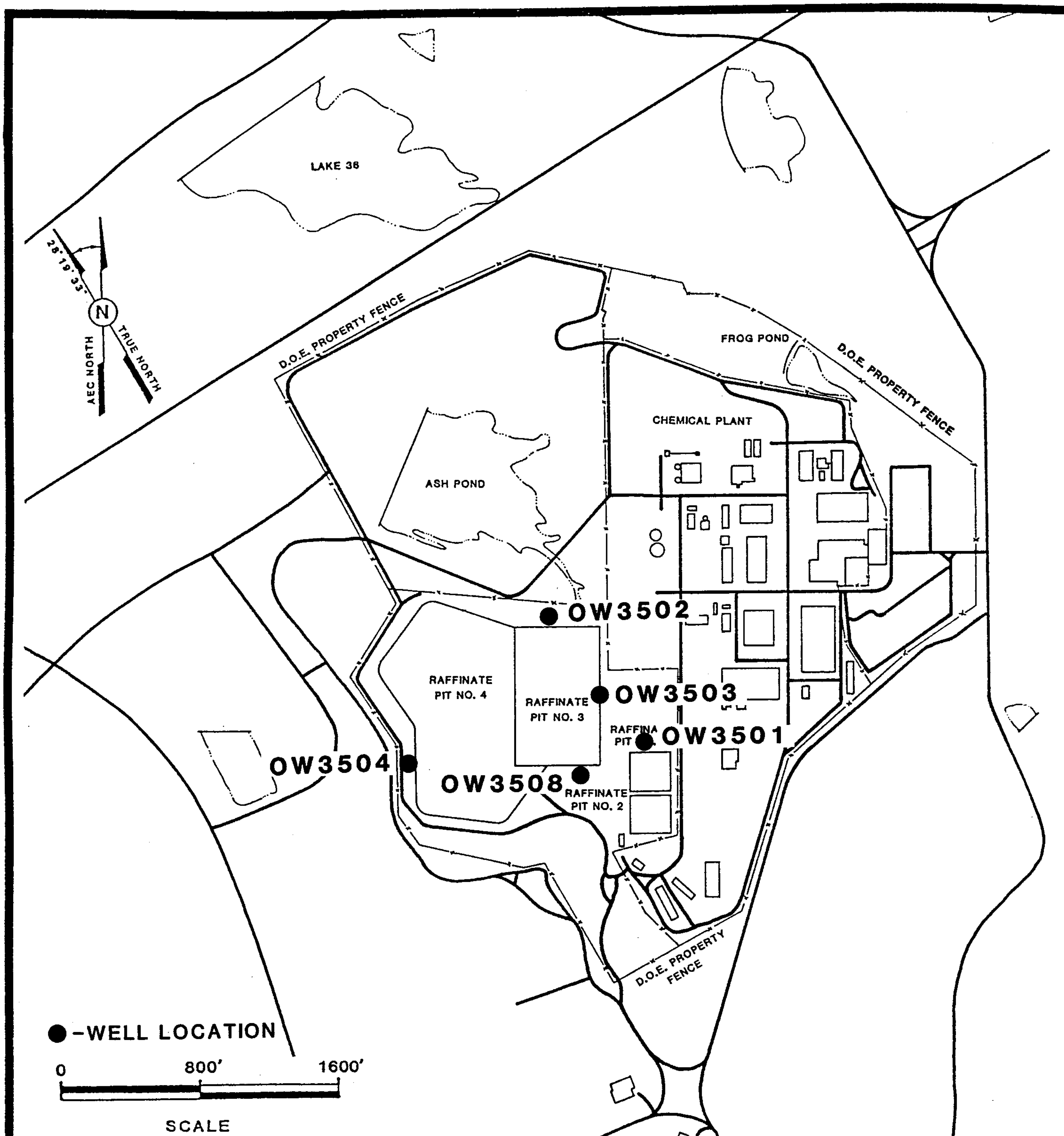


FIGURE 2-14

EXISTING OVERBURDEN MONITORING WELL LOCATIONS

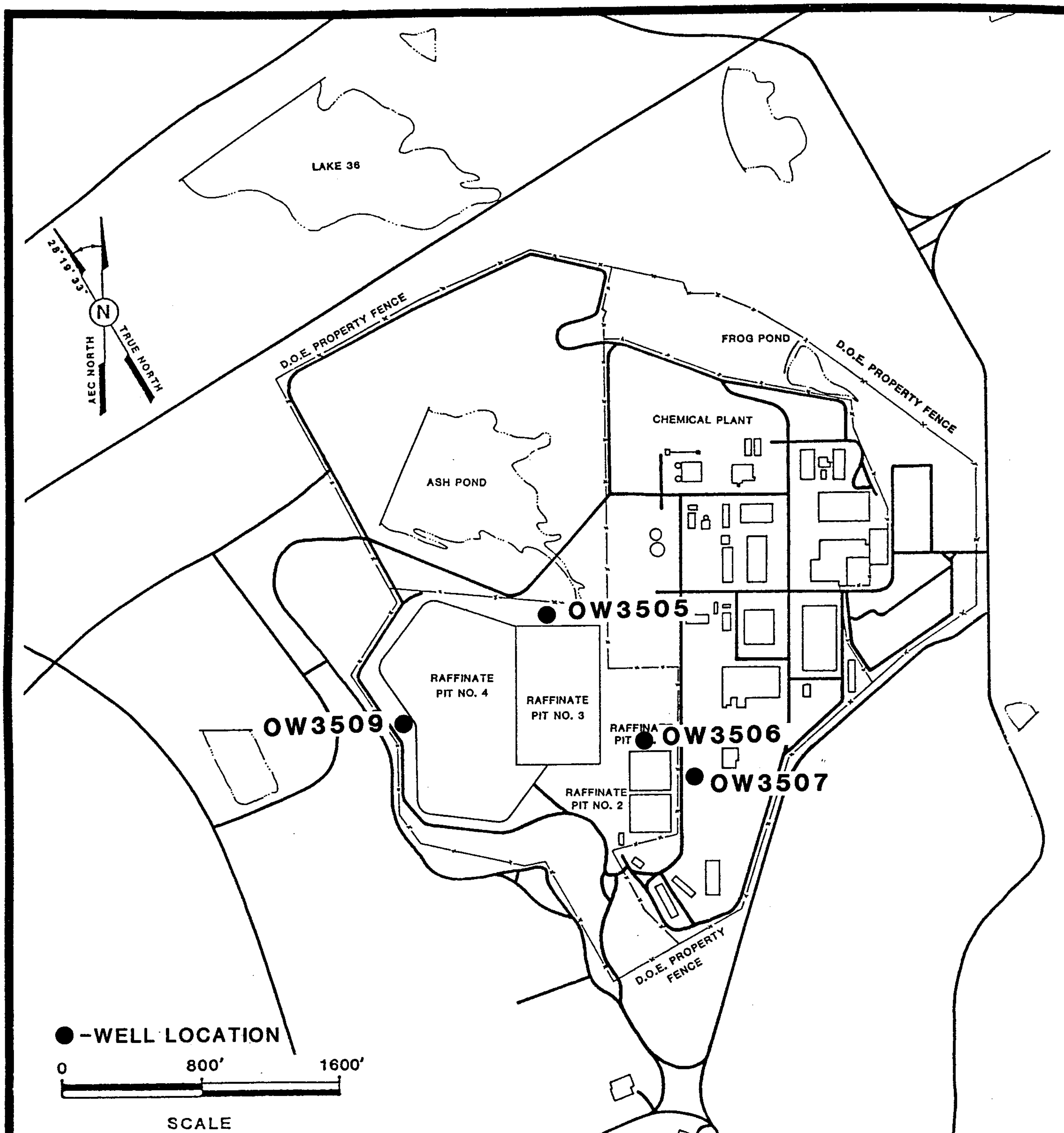


FIGURE 2-15

PROPOSED OVERBURDEN MONITORING WELL INSTALLATION LOCATIONS installation locations. These areas generally correspond to areas receiving recharge from leaking surface impoundments and/or areas disturbed by previous construction or landfilling activities. Table 2-7 presents a summary of overburden monitoring locations and rationale.

2.4.3.2 Drilling and Installation

Drilling operations for installation of overburden monitoring wells will be performed using hollow-stem augering methods. A supervising geologist will record a lithologic log for each borehole. Split-spoon samples will be collected at intervals of 5 feet, or where cuttings indicate particularly moist zones. Well depths will be adjusted based on field observations.

All drill bits, drill rod, casing, and hand tools will be decontaminated by steam-cleaning prior to beginning drilling and between boreholes. The entire drilling rig will be decontaminated upon arrival on-site.

Wells will be constructed using 2-inch inside diameter (ID) Schedule 40 PVC threaded, flush-jointed screens and casing. Screens will be slotted with 0.010-inch slots. Screen length will be 5 feet to allow sampling of a discrete saturated interval. PVC well materials were selected, since contaminants of concern are not deleterious to PVC and PVC is more readily removable when the wells are abandoned during final remedial action at the site.

Screens and casing will be decontaminated by steam-cleaning and wrapped or covered prior to installation. Screens and casing will be stored above ground to avoid contact with potentially contaminated soils.

The screen and casing will be lowered into the borehole using centralizers to insure that the well is plumb and centered in the

TABLE 2-7
OVERBURDEN MONITORING WELL PLACEMENT RATIONALE

Overburden Monitoring Well	Location	Rationale
OW-3505	North of Raffinate Pit 3, adjacent to OW-3502	Monitor mounding effects from Raffinate Pit 3; OW-3502, installed to monitor shallow seepage, is currently dry
OW-3506	North of Raffinate Pit 1, adjacent to OW-3501	Monitor mounding effects from Raffinate Pit 1; in combination with OW-3501 monitoring shallow seepage
OW-3507	Southeast side of Raffinate Pits 1 and 2	Monitor mounding effects from Raffinate Pits 1 and 2
OW-3509	West of Raffinate Pit 4	Monitor mounding effects from Raffinate Pit 4

borehole. A filter pack of coarse (20-40 mesh) sand will be placed around the screen by tremie pipe to a depth of 2 to 4 feet above the top of the screen.

A bentonite pellet seal will be placed above the filter pack. The minimum thickness will be 3 feet of dry pellets. The pellets will be allowed to set for at least one hour before work continues. The annular space will be sealed to the surface with cement/bentonite grout. A steel protective casing will be set in a concrete pad at the surface. Well construction details were presented previously in Figure 2-3.

2.4.3.3 Overburden Monitoring Well Development

After each well installation is complete and the grout has set for a minimum of 72 hours, each overburden monitoring well will be developed by bailing or pumping. All development equipment will be decontaminated by steam-cleaning before development begins and between wells.

A minimum of five volumes of standing water in the well and filter pack will be removed.

2.4.3.4 Groundwater Sampling

Groundwater sampling of perched and mounded zones will be performed in conjunction with the quarterly monitoring described in the Environmental Monitoring Program Plan. At least two rounds of sampling will be performed for inclusion in final reports and modeling efforts.

Groundwater samples will be collected using submersible bladder pumps and bailers according to WSSRAP Standard Operating Procedures. Measurements of pH, temperature, and specific conductance will be made in the field at the time of sampling.

Groundwater samples will be analyzed for the parameters listed above in Table 2-3.

2.5 SURFACE WATER STUDIES

Results from the Environmental Monitoring Program (EMP) sampling performed in 1987 and 1988 will be incorporated into the overall hydrogeologic characterization and used to determine the impact to surface water bodies of contaminants that may migrate from the WSS through runoff following precipitation or snowmelt. The following sections describe the surface water regime, and present known surface/subsurface connections; sample locations and analytical parameters are also given.

2.5.1 Surface Water Regime - WSCP/WSRP

Surface waters at the WSCP consist of Ash Pond, Frog Pond, and all drainages from both the WSCP and WSRP areas. Surface runoff from approximately 166 acres of the WSCP/WSRP area ultimately flows to the Mississippi River. Twenty-two acres drain toward the Missouri River. Drainages from the WSS are shown on Figure 2-16. The raffinate pits, comprising 27 acres, are impounded within the site, with no discharge.

Surface water from the 166 acres in the Mississippi River drainage is divided into three major drainage basins: Ash Pond area, Frog Pond area and the Raffinate Pits area. Both the Ash Pond area and the west side of Raffinate Pit No. 4 drain to an unnamed tributary to Schote Creek which flows to Lake 35. Both streams lose water to the subsurface. Some of this lost flow resurfaces at Burgermeister Spring (Dean, 1985). (Burgermeister Spring is considered "surface water" in the EMP.) Surface water from the Frog Pond exits the WSCP and flows into Lake 36. Overflow from Lake 36 enters Schote Creek and flows into Lake 35.

Lake 35 has lost water to the subsurface since its construction

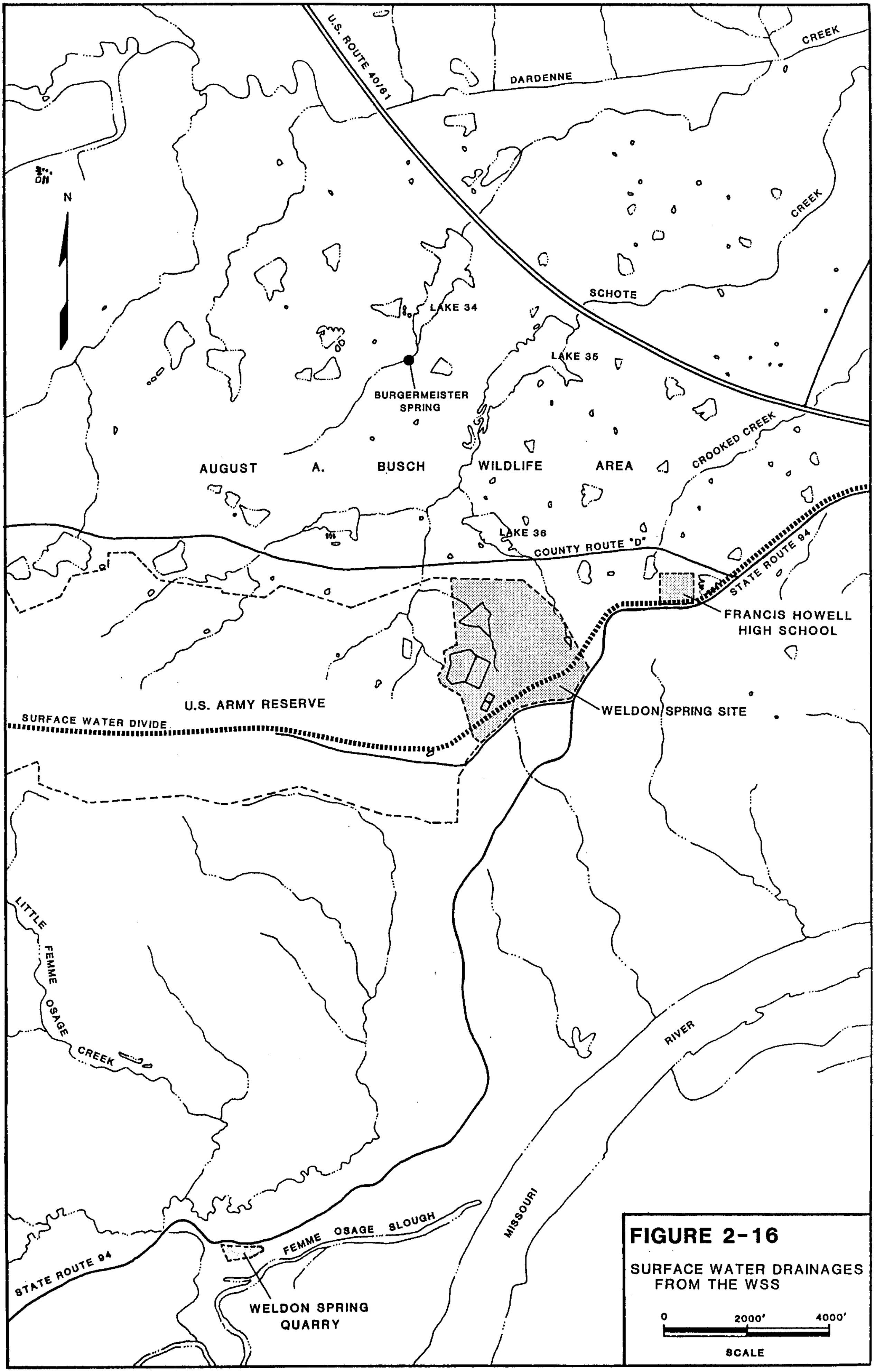


FIGURE 2-16

SURFACE WATER DRAINAGES FROM THE WSS

(Meyer, 1987). Lake 35 overflows to Schote Creek only during extreme precipitation events. Schote Creek joins Dardenne Creek just east of Highway K.

In early 1987, a small swallow hole opened near the headwaters of Lake 35. Missouri Department of Natural Resources dye studies determined that some of the lost water resurfaces in Lake 34 and at a spring just north of Lake 34. Subterranean flow surfacing at Burgermeister Spring flows into Lake 34. Lake 34 outflow enters an unnamed tributary of Dardenne Creek (Figure 2-16). Dardenne Creek flows northeast to the Mississippi River.

The 20 acres of the site that is in the Missouri River drainage is located in the southeast portion of the WSCP. Drainage is via the Southeast Drainage Easement, an intermittent stream valley approximately 1.5 miles long.

Surface water sampling programs have also been performed to support National Pollution Discharge Elimination Standard (NPDES) permits associated with sanitary waste and storm-water runoff. One permit for discharge of sanitary waste through the Imhoff tank expired on December 31, 1986. Sampling consisted of bi-monthly sampling for nitrate, BOD, pH and total suspended solids. In 1986 the DOE applied for a storm-water runoff NPDES permit for the WSCP/WSRP. This permit application is for storm water only; no process waste or other routine discharges occur. Samples collected monthly from five storm-water outfalls are analyzed for gross alpha, natural uranium, nitrate, total suspended solids, total settleable solids and pH. These results are reported to the MDNR according to NPDES procedures. NPDES surface water sampling points are shown on Figure 2-17.

2.5.2 Surface Water Sampling Program

Surface water samples will be collected from 19 locations as shown in Figures 2-17 and 2-18. The rationale for each location

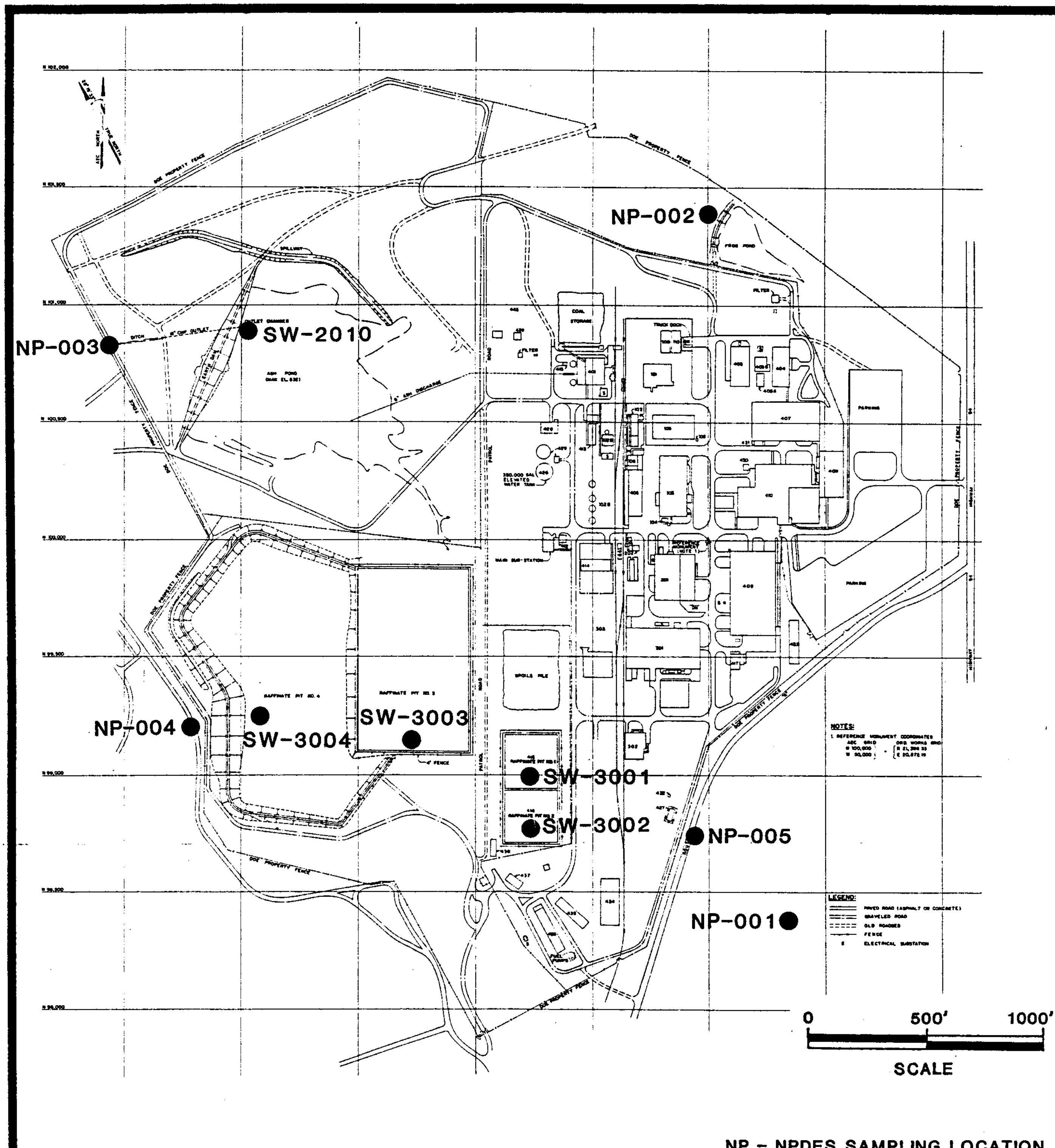


FIGURE 2-17

ON-SITE SURFACE WATER SAMPLING POINTS

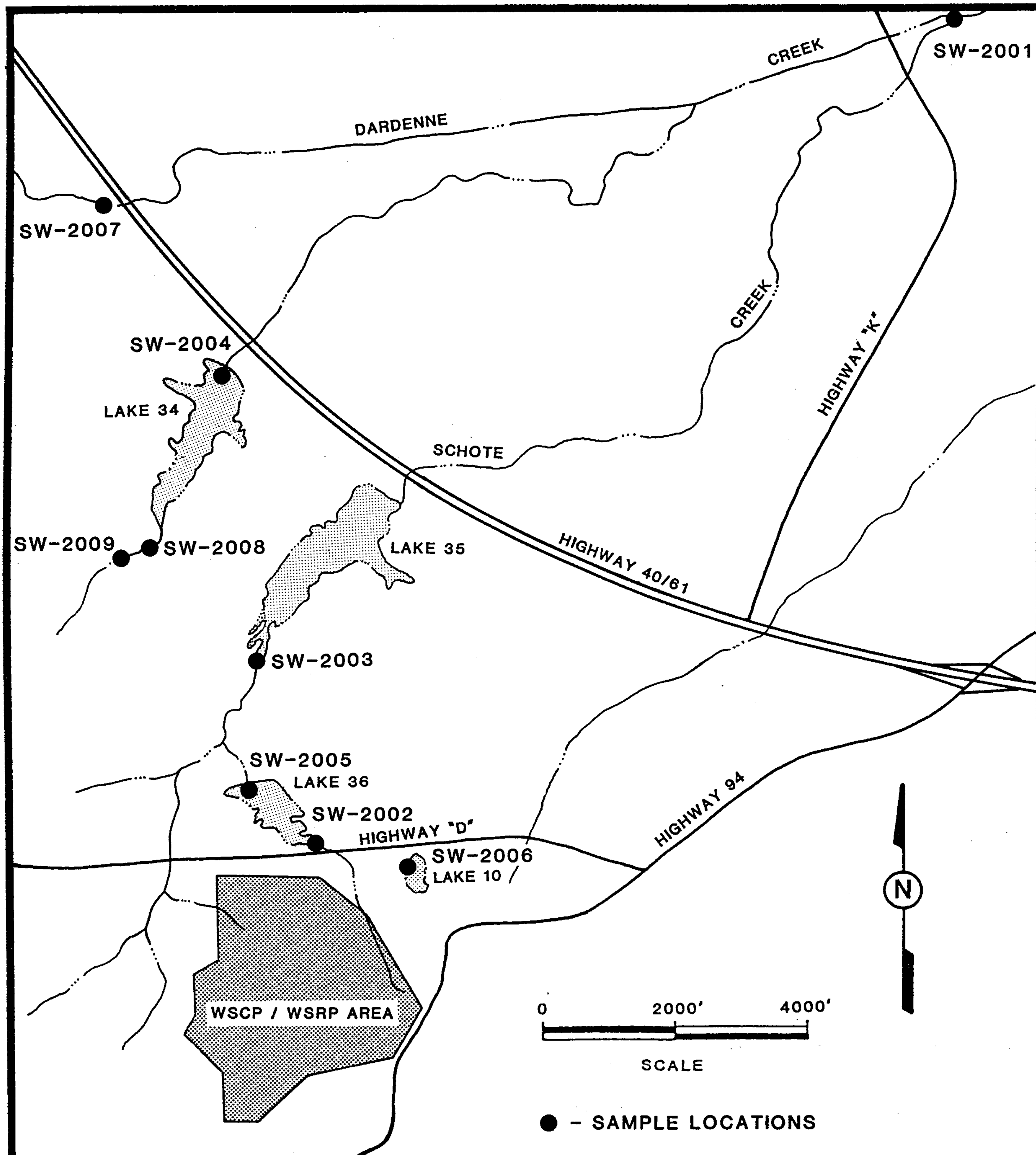


FIGURE 2-18

SURFACE WATER SAMPLING LOCATIONS NEAR THE WSS is presented in Table 2-8. Samples will be collected concurrently with quarterly groundwater sampling to provide point-in-time comparisons of groundwater and surface water sampling results.

These locations include the five NPDES storm-water discharge points which are currently sampled monthly, nine locations currently sampled under the EMP, the four raffinate pits and Ash Pond. The analytical results will provide water quality information for streams draining the site (some of which lose water to the subsurface), springs discharging potentially contaminated groundwater, and on-site source areas.

Samples will be collected in accordance with procedures outlined in the WSSRAP SOPs.

Analytical parameters for surface water samples include: nitroaromatics, metals, inorganic anions and radionuclides. Parameters were selected based on the results presented in the Phase I Water Quality Assessment, known processes at the WSCP and previously collected data. Complete analytical parameters are presented in Table 2-9.

2.6 REGIONAL HYDROGEOLOGY AND WATER BALANCE

The U.S. Geological Survey (USGS) will perform studies of regional hydrogeology and water balance culminating in the development by the USGS of a three-dimensional regional groundwater flow model. Additional USGS efforts will focus on site-related water quality issues and will serve to provide third-party verification of WSSRAP efforts.

2.6.1 Regional Groundwater Flow and Water Balance

USGS studies will provide further refinement of regional hydrogeology as presented in previous USGS publications and

TABLE 2-8

PROPOSED SURFACE WATER SAMPLING LOCATIONS

SAMPLE NUMBER	LOCATION	RATIONALE
NP-001 to NP-005	NPDES outfall (5)	Assess off-site releases due to precipitation events
SW-2001	Dardenne Creek (at junction with Schote Creek)	Assess downstream water quality-receives groundwater discharge from vicinity of WSS
SW-2002	Schote Creek (down-stream of WSCP immediately upstream of Lake 36)	Assess creek water quality - receives direct surface run-off from WSCP
SW-2003	Lake 35 (Busch Area-upstream side of bridge at head of Lake 35)	Assess lake water quality - receives direct surface run-off
SW-2004	Lake 34 (Busch Area, midpoint of dam)	Assess lake water quality - leaving lake to Dardenne Creek
SW-2005	Lake 36 (Busch Area, midpoint of dam)	Assess lake water quality - leaving lake to Schote Creek
SW-2006	Lake 10 (Busch Area, midpoint of dam)	Assess lake water quality
SW-2007	Dardenne Creek (at upstream side of Highway 40-61 bridge)	Establish background water quality upstream of WSCP
SW-2008	Burgermeister Spring	Assess water quality of spring discharge
SW-2009	Overflow Spring	Assess water quality of spring discharge

TABLE 2-8 (cont.)

PROPOSED SURFACE WATER SAMPLING LOCATIONS

SAMPLE NUMBER	LOCATION	RATIONALE
SW-2010	Ash Pond	Assess on-site water quality
SW-3001	Raffinate Pit 1	Assess potential source area
SW-3002	Raffinate Pit 2	Assess potential source area
SW-3003	Raffinate Pit 3	Assess potential source area
SW-3004	Raffinate Pit 4	Assess potential source area

TABLE 2-9

SURFACE WATER ANALYTICAL PARAMETERS

pH *
Temperature *
Conductivity *
Total Uranium (Natural)
Total Radium-226
Total Thorium-230
Gross Alpha
Gross Beta
Nitrate
Sulfate
Fluoride
Chloride
Nitroaromatics
CLP Metals

*Field Measurement

comprehensive water balance measurements. The USGS will combine these results with WSSRAP data obtained from the field programs outlined in Sections 2.2 through 2.5, to produce a regional groundwater flow model encompassing the shallow aquifer in the Burlington-Keokuk Formation, the leaky confining layer, and deep aquifers in the sequence from the St. Peter Formation through the Potosi Dolomite.

Potentiometric surface maps will be derived from water-level measurements in groundwater monitoring wells installed on-site by WSSRAP, from USGS monitoring wells located on the Busch Wildlife Area to the north of the site, and from various private wells around the site that are suitable for monitoring and sampling. These maps will extend beyond the immediate vicinity of the site covered by the WSSRAP potentiometric surface maps discussed above in Section 2.1.3.

Continuous water level recorders will be installed on six wells near the groundwater flow divide south, east, and northeast of the raffinate pits (Figure 2-19). Daily fluctuations in the groundwater levels will be correlated with precipitation, evapotranspiration, infiltration and barometric fluctuations in order to evaluate and determine the role of each of these factors on the water balance of the plant site. Also, data collected will be used to define the direction of groundwater flow. The locations of the six wells are subject to change as new data are received and analyzed from the drilling program.

Twelve aluminum infiltration tubes (2 3/8 inch OD) will be installed in various soils on the WSS and vicinity properties as shown on Figure 2-20 in order to measure soil moisture content. Use of a neutron probe is a nuclear method of determining moisture content and porosity of soil as described in Sections 2.4.1.2, 2.4.1.3 and 2.4.1.4.

The data that is obtained from neutron probe measurements will be

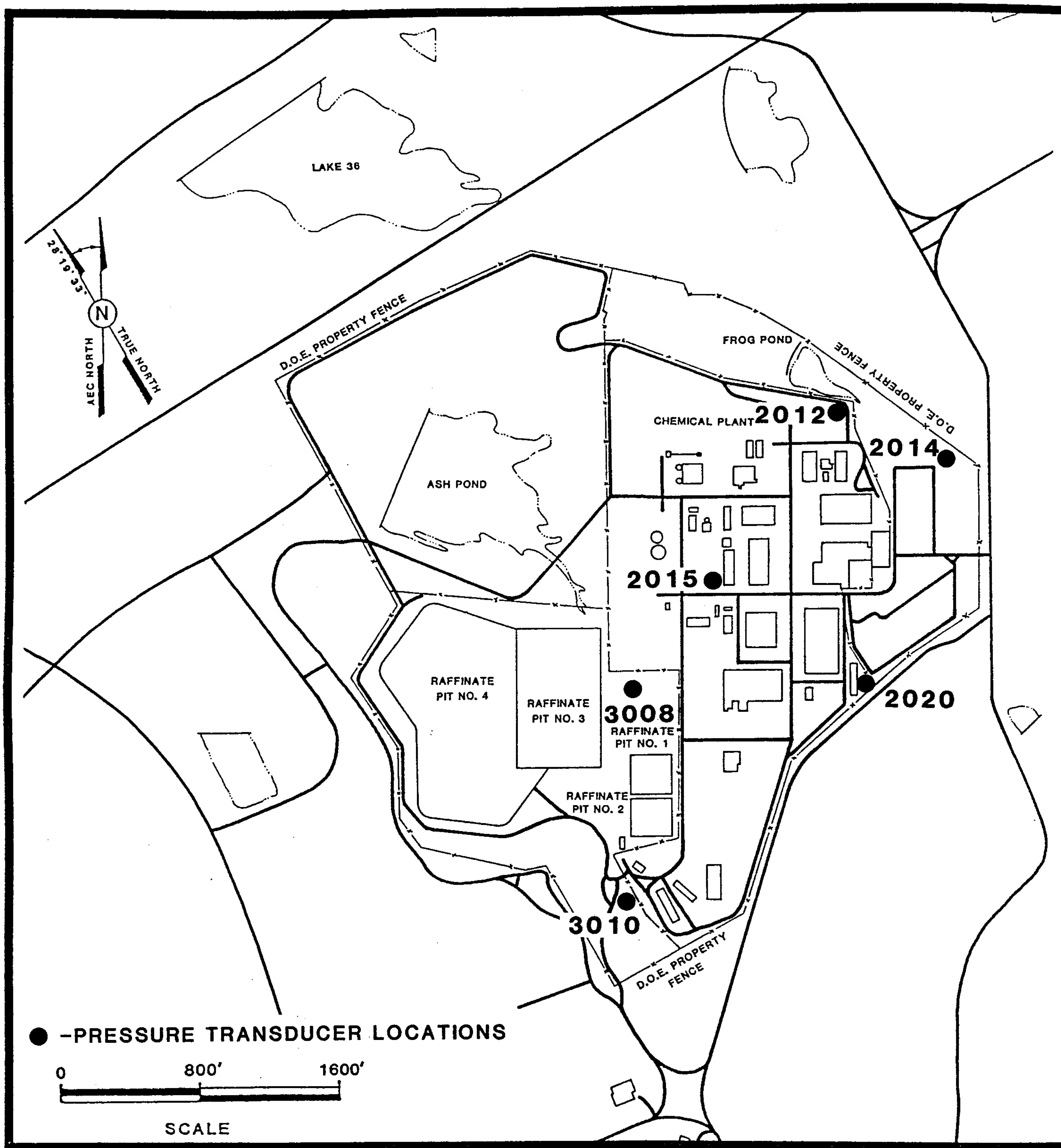


FIGURE 2-19

EXISTING MONITORING WELLS TO BE EQUIPPED WITH CONTINUOUS WATER LEVEL RECORDERS

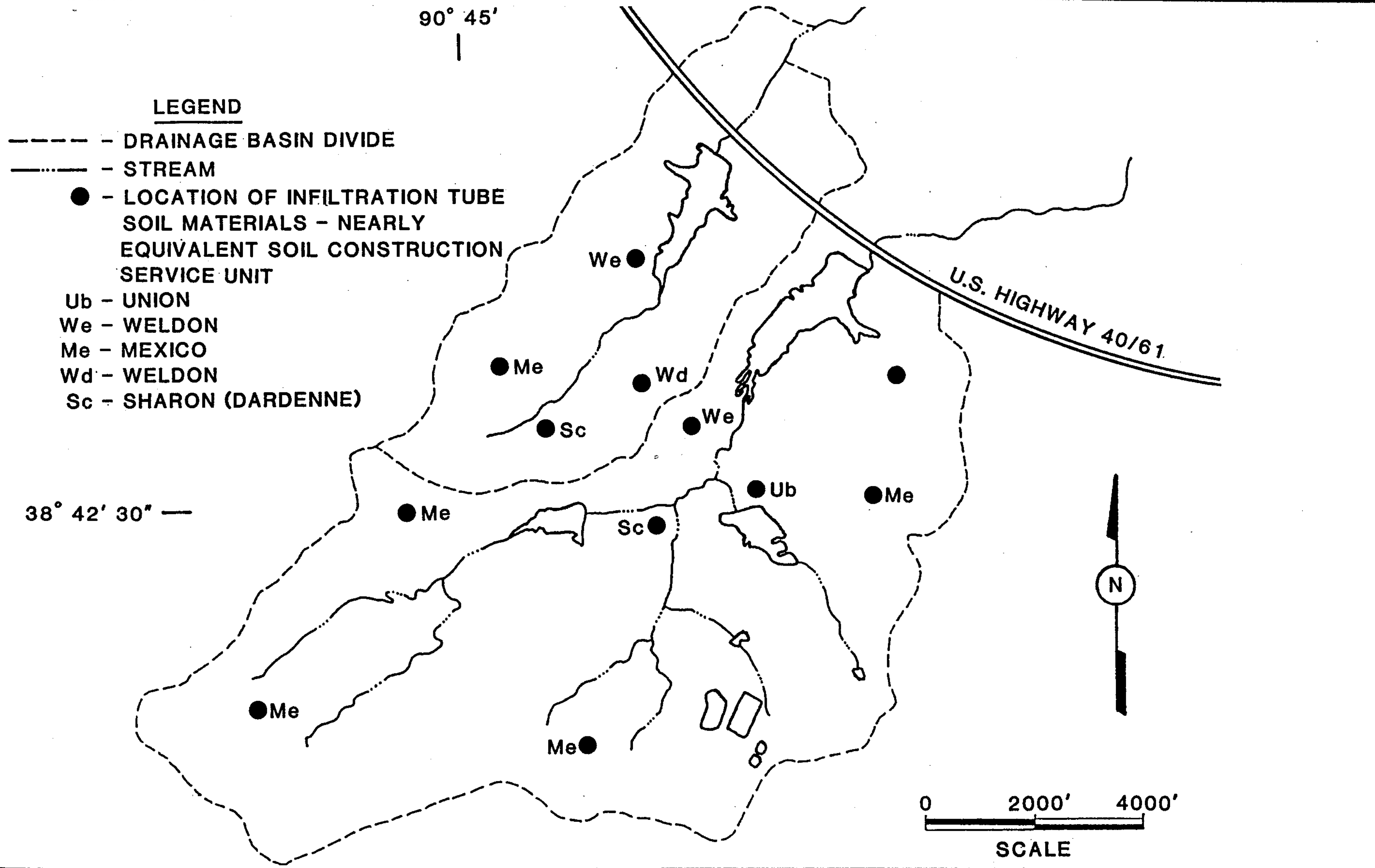


FIGURE 2-20

LOCATION OF INFILTRATION TUBES

used to monitor the saturation of unconsolidated overburden and provide an estimate of evapotranspiration. These data will allow an estimate of the quantity of water that infiltrates into the aquifers and, when compared with precipitation data, will assist with the determination of the water balance.

The regional groundwater flow study will include the installation of two clusters of deep monitoring wells by WSSRAP at the locations shown on Figure 2-21 in order to determine vertical gradients between the shallow and deep aquifers underlying the site. Water samples from various depths and aquifers will be analyzed to determine water quality differences. One well cluster will be located immediately south of the site near the groundwater flow divide. This location was selected to monitor vertical gradients near the groundwater flow divide, which will constitute a no-flow zone (at least in the Burlington-Keokuk Formation) in the regional groundwater model. The second well cluster will be located near Dardenne Creek which is at a lower topographic elevation and is considered to be a hydrogeologic boundary for shallow groundwater flow. Monitoring of vertical gradients at this location will help to determine the depth to which regional groundwater flow in the shallow aquifer, leaky confining layer, and deep aquifer is affected by discharge to Dardenne Creek. Comparison of differences in vertical gradients between the immediate vicinity of the site and Dardenne Creek will allow for accurate calibration of the regional flow model.

Each observation well cluster will consist of one well with the screened sector in the Burlington-Keokuk Limestone Formation at a depth of approximately 100 feet, one well with the screened sector in the Kimmswick Limestone Formation at a depth of approximately 300 feet, and one well with the screened sector in the St. Peter Sandstone Formation at a depth of approximately 700 feet. The cluster immediately south of the site will consist of two deep wells clustered with an existing monitoring well screened in the Burlington-Keokuk Formation (MW-4019). A

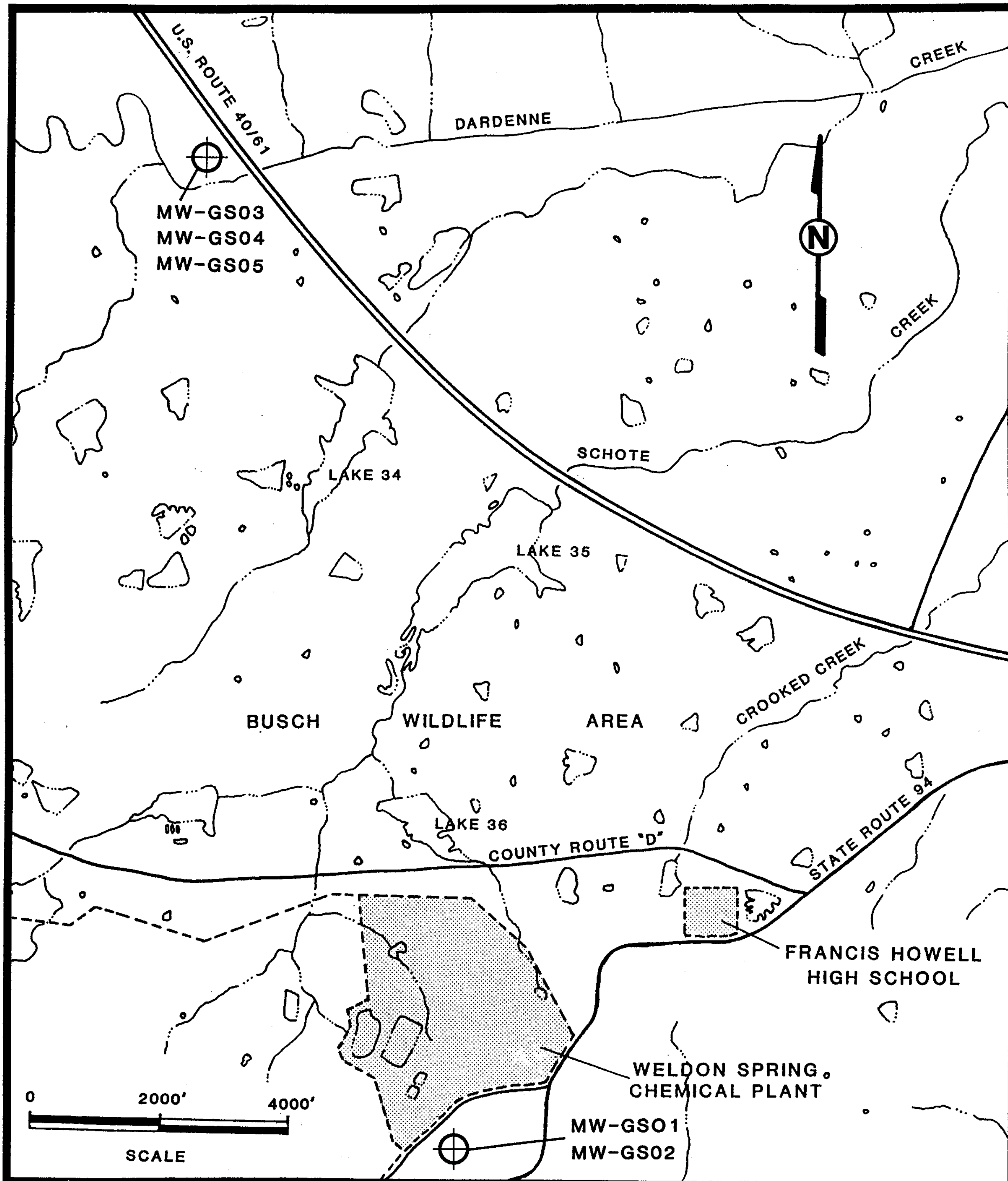


FIGURE 2-21

MONITORING WELL CLUSTER LOCATIONS

geologist will monitor drilling progress, collect rock samples from cores and drill cuttings and ensure compliance with WSSRAP Standard Operating Procedures.

Surface features that relate to groundwater accumulation, movement, or quality will be investigated in depth for the purpose of developing the groundwater flow model. Springs, seeps, losing stream segments, gaining stream segments, karst features in limestone bedrock, fractures, joints, geological structures and any additional phenomena which may become evident during the course of field efforts will be investigated for the purpose of determining effects on water balance and flow characteristics. This portion of the investigation will be performed in cooperation with the Missouri Department of Natural Resources, Division of Geology & Land Survey.

Remote sensing, aerial photographs, side-looking radar, infrared photography and other methods may be employed to delineate surface features. A field reconnaissance program will be conducted in order to locate and define these features and to quantify their effects.

Flow and discharge data from the continuously recording stream gauging stations currently in place on Schote Creek and the unnamed Dardenne Creek tributary which contains Burgermeister Spring will also be used in water balance studies.

Continuous discharge monitoring of Burgermeister Spring will permit comparison of the effects of various weather conditions on spring discharge and chemical quality. Surface water discharge will be compared with other monitored parameters including water table fluctuations, barometric changes, precipitation, temperature, humidity, evapotranspiration and infiltration.

Precipitation amounts will be measured during the spring, summer, and fall months with 19 catch rain gages located in the basins of

Schote Creek and the unnamed tributary that contains Burgermeister Spring (Figure 2-22). The total area of these two basins is about 4.6 square miles. Because of the variability of precipitation during localized thunderstorms during these months, these 19 rain gages are needed. During the winter when storms are regional in nature, the number of rain gages will be reduced to nine. Rainfall amounts will be calculated using both the isohyetal and Thiessen methods. The rainfall data will be used to accurately determine the amount of precipitation within these two basins for utilization in water balance calculation and groundwater flow modeling calibration.

The regional groundwater flow model will be constructed using the USGS 3-Dimensional Groundwater Flow Model (MOD). Vertical extent of the model will be from the surface (Burlington-Keokuk Formation) to the base of the Potosi Dolomite. Tentative horizontal boundaries are constant-head or constant-flow boundaries at the Missouri River and Dardenne Creek to the north and south and no-flow boundaries along major drainage divides to the east and west. Data used to construct the model will include the potentiometric surface and water balance data discussed above and aquifer testing data from WSSRAP efforts discussed above in Section 2.2.

2.6.2 Water Quality

USGS studies include both surface and subsurface water sampling. Water samples will be collected on a quarterly basis from USGS monitoring wells in the Busch Wildlife Area, selected private wells, and selected surface water locations. These data will be combined with WSSRAP data for a regional analysis. The statistical analysis of water quality data will form the data base for the description of the groundwater chemistry. The preliminary list of analytical parameters to be tested is presented on Table 2-10.

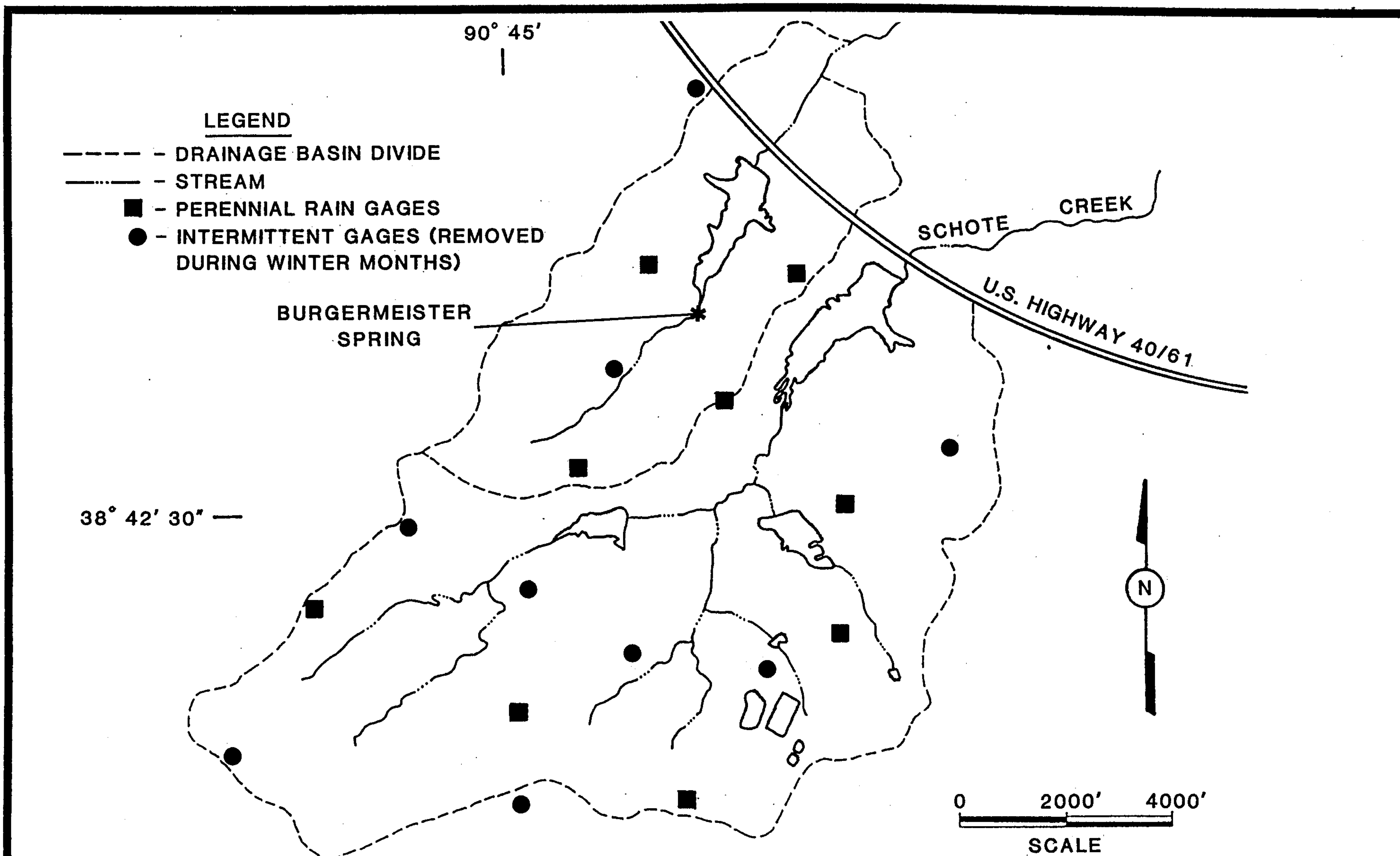


FIGURE 2-22

LOCATION OF USGS RAIN GAGES

TABLE 2-10

ANALYTICAL PARAMETERS FOR USGS WATER QUALITY STUDIES

Specific Conductance

pH

Temperature

Total Organic Carbon

Dissolved:

Calcium	Carbonate
Magnesium	Bicarbonate
Potassium	Sulfate
Lithium	Nitrate
Strontium	Chloride
Uranium	Fluoride
Radium-226	Solids
Sodium	

In addition to the listed parameters, samples will be analyzed for tritium, radium-228 and nitroaromatics on a one-time-only basis unless elevated concentrations are discovered. In the event of the identification of samples containing concentrations above background level, additional sampling and analysis would be conducted in order to further define the extent and concentration of the contaminants in the areas affected.

Continuously recording temperature and specific conductance monitors ("mini-monitors") were installed at Frog Pond, Ash Pond and Burgermeister Spring in 1987 (Figure 2-23). These monitoring sites will continue to be operated to determine how water quality varies with time, climatic conditions and remedial action activities conducted on the site.

The geochemistry of the natural unconsolidated overburden sediments on the site will be investigated in order to determine its effect on contaminant migration. Once the water balance has been determined, these data will be instrumental in determining the locations of contaminant plumes and predicting the direction and rate of plume migration.

2.6.3 Computer Modeling of Chemical and Mineralogical Balance

Geochemical models including WATER and BALANCE will be used in determining the normal chemical balance for groundwater underlying the Weldon Spring Site. WATER calculates the equilibrium distribution of inorganic aqueous species of both major and minor chemical elements. BALANCE defines and quantifies the reactions that will occur between groundwater and naturally occurring minerals in the aquifers.

Data required for these programs include aqueous chemistry and quantitative mineralogy. The aqueous chemical data will be derived from the analysis of the water samples collected from

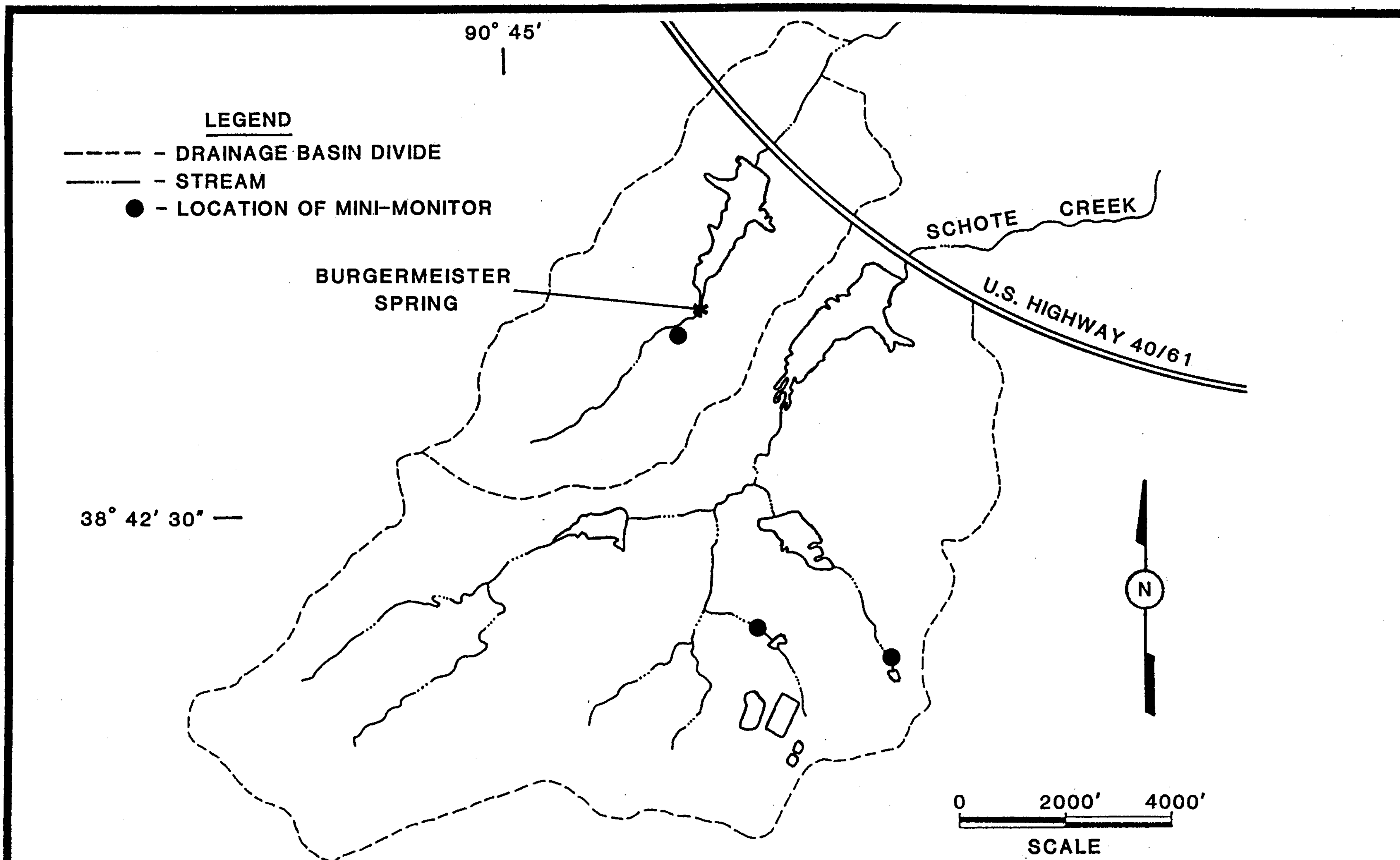


FIGURE 2-23

LOCATION OF USGS MINI-MONITORS

groundwater monitoring wells, and springs and streams on and near the site. The quantitative mineralogy will be determined from cores and overburden samples from wells drilled and trenches cut in both the unconsolidated overburden sediments and the bedrock formations underlying the Weldon Spring Site. The percent of clay minerals and non-clay minerals, as well as the types of clays present at the Weldon Spring Site will be determined. Soil samples will be collected from each of the soil horizons present at approximately a dozen locations distributed throughout the site. Mineralogic analyses will be performed by USGS laboratories.

2.7 COMPUTER MODELING OF GROUNDWATER FLOW SYSTEMS

Groundwater flow models will be developed in order to define and describe the flow regime in the shallow bedrock aquifer underlying the Weldon Spring Site and to predict contaminant migration in this flow regime. These models will be developed by the Department of Geological Engineering of the University of Missouri-Rolla in cooperation with WSSRAP staff. This site-specific modeling is designed to complement the regional modeling performed by USGS.

Models of unsaturated flow, groundwater flow, and contaminant transport will be calibrated to match the field parameters at the Weldon Spring Site. Statistical analyses including probability and uncertainty will be performed to establish reliability of the groundwater flow models.

2.7.1 Computer Programs

Three simulation programs have been chosen for the project because each has certain desirable properties that fit the groundwater flow system at the Weldon Spring Site. Use of these programs will help to identify groundwater flow direction and contaminant transport. The models include the following software:

- o A Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MOD).

- o Saturated and Unsaturated Transport Flow Model (SUTRA).

- o Three-Dimensional Flow and Transport Model (SWIP).

MOD and SWIP are three-dimensional models and SUTRA is a two-dimensional model. Should new parameters arise during the course of field work which are not applicable to MOD, SWIP, or SUTRA, additional software is available to accommodate any additional parameters.

2.7.2 Model Design

Three basic steps are required for the general model design process including: (1) development, (2) calibration, and (3) verification. The development step involves the determination of which parameters are available from the compilation of field studies and which parameters must be derived during the process of calibration and tuning of the program to produce verifiable results.

Calibration is accomplished by modifying and adjusting the undefined parameters until the computed water levels match historical field water levels as measured during a discrete period of time. Unspecified aquifer parameters may include dispersivity, hydraulic conductivity, storativity and others. Field data will not provide perfect definition of all parameters. For some parameters the models will exhibit high sensitivity, while others will have minimal effect on model results. Sensitivity analysis is accomplished by slightly varying a single parameter while all other parameters are held constant. The variation may be repeated over differing typical ranges of a given parameter's value. Models which are essentially insensitive to a given parameter do not require extensive field data. Models which are very sensitive to a given parameter may ultimately require both extensive and intensive field studies in order to adequately calibrate the computer model.

Verification is accomplished by employing a period of historical water level data which was not used in the model calibration process. The model is verified when the computed and measured water levels match. A poor match requires additional calibration until such time as repeatable verification can be established.

2.7.3 Model Application

Practical application of the computer modeling effort is divided into three separate phases based on the hydrogeologic conditions at the Weldon Spring Chemical Plant and Raffinate Pits sites.

- Phase 1 will focus on the contaminant transport in the shallow unsaturated zone using SUTRA which is a two-dimensional unsaturated transport model. This model will be calibrated and verified and the results will be used to predict recharge rates, which will be used to develop constant flow boundary conditions for use in Phase 2.

- Phase 2 will use MOD, a three-dimensional flow model, to predict contaminant transport in the saturated, fractured bedrock aquifer system. This aquifer will initially be modeled as an equivalent porous medium. The fracture system in this bedrock formation will ultimately be accounted for by imbedding high conductivity zones within the less conductive equivalent porous medium matrix. This model will be calibrated and verified and the results will be used in the development of the Phase 3 model.

- Phase 3 will evaluate contaminant transport along vertical sections of the fractured and saturated bedrock aquifer using SWIP, a three-dimensional contaminant transport model. Results from Phases 1 and 2 will be used in the development of the Phase 3 model. The Phase 1 model will supply boundary data and the Phase 2 model will provide steady-state flow conditions, which are parameters necessary for the development of the Phase 3 contaminant transport model.

Parameters needed for the purpose of accurate model calibration include:

- Vertical variation of soil contamination: This will be determined by soil sampling and analysis.

- Flow characteristics in the unsaturated zone: This will be measured by neutron probes and tensiometers as discussed in Section 2.4.1.

- Transmissivity in the fractured bedrock aquifer: Field methods for the determination of aquifer transmissivity by pumping tests are discussed in Section 2.2.2.

- Major conduit forming fractures or fracture zones: The location, orientation and configuration of bedrock fracture systems will be determined through the integration and interpretation of all available subsurface surveys, both direct and indirect.

Open fracture systems will constitute the major controlling geological feature in any groundwater flow system in which they occur and must be incorporated into the flow model. The size and extent of such features should be mapped as accurately as possible. Aperture width, fracture spacing and the nature of any filling materials should be measured as accurately as practicable within the limitations of the current prevailing field technology.

The final verified models will be used to evaluate the potential for significant contaminant migration in the shallow bedrock aquifer from the Weldon Spring Chemical Plant and Raffinate Pits sites to adjacent areas of beneficial use. The models will also be utilized in the planning, evaluation and development of various subsurface restoration/mitigation options that may be considered in future site remediation plans.

2.7.4 Model Uncertainty

Model uncertainty is an inherent quality that is directly related to the sophistication of the model design. The more variable parameters that are properly recognized, treated and manipulated in the model design, development and calibration, the more accurately the model will imitate the natural phenomena under investigation.

An important aspect of model uncertainty is the quality of the raw field data used as input to the modeling process. It is imperative that as many variable parameters as possible be identified and accurately measured in the field. Field investigations are an integral aspect of the program in progress at the site. Field research includes soil and water quality sampling from groundwater monitoring wells, water quality and discharge measurement from several surface streams and springs and continuous recording of water levels in several ponds and streams.

The additional groundwater monitoring wells installed during 1988 will better define areas of contamination and flow patterns (Section 2.1.1.2). Slug tests (Section 2.2) and pumping tests (Section 2.2.2) will be employed in the determination of hydraulic conductivity, transmissivity, storativity and anisotropy--parameters which will be utilized in the process of calibrating the computer models.

A site-specific investigation of the fractured limestone bedrock aquifer will include the identification of controlling fractures, fracture zones and fracture systems. The fracture system will be studied by means of field identification, measurement and mapping, and analysis of aerial photographs and topographic maps. The effect of fractures on the groundwater flow regime will be determined by comparing the configuration of the piezometric surface of the shallow bedrock aquifer to the orientation of the individual components of the integrated fracture system. Direct comparisons of these parameters will help to clarify their relationship and interdependence within the shallow groundwater aquifer.

Statistical analysis of the field and laboratory data used as input to the models will give some quantification of parameter uncertainty. Simple analytical and numerical approaches may be used to evaluate the uncertainty of predictions of groundwater flow and contaminant transport predictions. The statistical analyses of input parameters (i.e., groundwater velocity, initial source concentration, etc.) will be used to qualitatively and quantitatively evaluate the reliability of predicted flow and concentrations at a particular location and time. These measures of uncertainty, though based on simplified solution models, will provide additional information for utilization in field data acquisition and planning of remedial actions.

3.0 <u>DOCUMENTATION</u>

All field activities performed by WSSRAP staff and subcontractors will be thoroughly documented by a combination of chronological field notes encompassing all field activities, photographs of field activities, and data forms for drilling, well installation, specific sampling activities and field measurements. Field activities performed by other governmental agencies (Missouri Department of Natural Resources--Division of Geology and Land Survey and U.S. Geological Survey) will be documented under procedures established by those agencies.

3.1 FIELD NOTEBOOKS

During the course of monitoring-well installation and development, pumping-test-well installation and development, field implementation of unsaturated zone monitoring instruments, and aquifer testing, a designated field geologist or engineer will record daily activities in a permanently bound, waterproof and paginated notebook. Entries in this notebook will include:

- The date
- Weather conditions
- All personnel involved, including subcontractor and governmental agency personnel
- Chronological record of the day's activities. A description of each activity, and the time (24-hour clock) will be entered. Any measurements or other information that are not recorded on designated field forms will be recorded in the field notebook.

All entries will be made in waterproof ink. When errors are made, they shall be crossed out with a single line and initialed by the designated field geologist or engineer. The field geologist or engineer will sign the notebook at the end of each day.

3.2 PHOTOGRAPHS

Photographs will be taken of representative activities for each hydrogeologic subtask. Photographs will be taken of activities at each stage of each subtask: installation, sampling, logging of core, testing, measurements, etc. Log entries will be made in the field notebook that identify the location and activity depicted in each photograph. Each entry into the field notebook photographic log will include the name of the photographer, the date, the location, description of activities, and identity of each person in the photograph. Photographs will be retained in WSSRAP Document Control.

3.3 FIELD FORMS

Field data forms have been developed for borehole logging, well installations, well development, and sampling activities under this Hydrogeologic Sampling Plan. Instructions for completing each form are included in the WSSRAP Standard Operating Procedure (SOP) for each activity. A brief description of the information to be documented on each form is presented below.

3.3.1 Borehole Logging

This subsection presents a description of the documentation procedures for borehole logging activities at the WSSRAP. Borehole logs are used to keep a detailed record of drilling and exploratory excavations on a prepared form, and include geological descriptions of both soil and rock.

A borehole log form (Figure 3-1) will be used when drilling in both soils and rock. The following information will be entered on the heading of each log sheet:

- Boring or well number
- Location

WELDON SPRING SITE REMEDIAL ACTION PROJECT
BOREHOLE LOG

PAGE _____ OF _____

SITE ID: __________ LOCATION ID: __________
SITE COORDINATES (FT.): __________
N __________ E __________
GROUND ELEVATION (FT. MSL): __________
DRILLING METHOD: __________
DRILLING CONTR.: __________
DATE STARTED: __________
DATE COMPLETED: __________
FIELD GEOLOGIST/ENGINEER: __________

GROUNDWATER LEVELS		
DATE	TIME	DEPTH (FT.)

LOCATION DESCRIPTION __________

SITE CONDITION __________

DEPTH	SAMPLE INTERV.	SAMPLE RECOV.	CPM (OPT.)	BLOWS PER 6 IN.	N VALUE	VISUAL CLASSIFICATION

COMMENTS: __________

FIGURE 3-1: WSSRAP BOREHOLE LOG

- Elevation
- Name of drilling contractor
- Drilling method and equipment
- Water levels
- Start and finish (time and date)
- Name of geologist/engineer responsible for logging
- Description of site conditions

The following technical information is recorded on the logs:

- Depth of sample below surface
- Sample/core interval
- Length of sample recovered
- Counts per minute (cpm) as recorded by a Geiger-Mueller Pancake Detector (optional - used in areas with potential radiological contamination)
- Standard Penetration Test (ASTM-D1586) results as applicable
- Visual classification containing a soil or lithologic description
- Total depth of the borehole

All pertinent observations about drilling rate, equipment operation, or unusual conditions will be recorded.

Soil descriptions will be in accordance with the Unified Soil Classification System (USCS) as described in ASTM D 2487-69 (1975) and should stress major constituents and characteristics. The following format for soil descriptions will be used:

1. Soil name
2. Gradation or plasticity
3. Particle size distribution
4. Color
5. Moisture content

6. Relative density or consistency
7. Soil texture and structure
8. Relative permeability
9. Local geologic name
10. USCS classification

Rock descriptions will include the following:

1. Lithology and texture
2. Color
3. Hardness
4. Weathering
5. Grain size
6. Description of bedding and/or jointing
7. Discontinuity descriptions
8. Local geologic name
9. Percent recovery of core
10. RQD of core samples

3.3.2 Well Completion Diagrams

A monitoring-well completion diagram (Figure 3-2) will accompany each monitoring well installed. The form will contain the following information:

- Well number
- Location
- Geologist or engineer
- Well installation date
- Drilling contractor

Monitoring-well construction details to be included on the diagram are as follows:

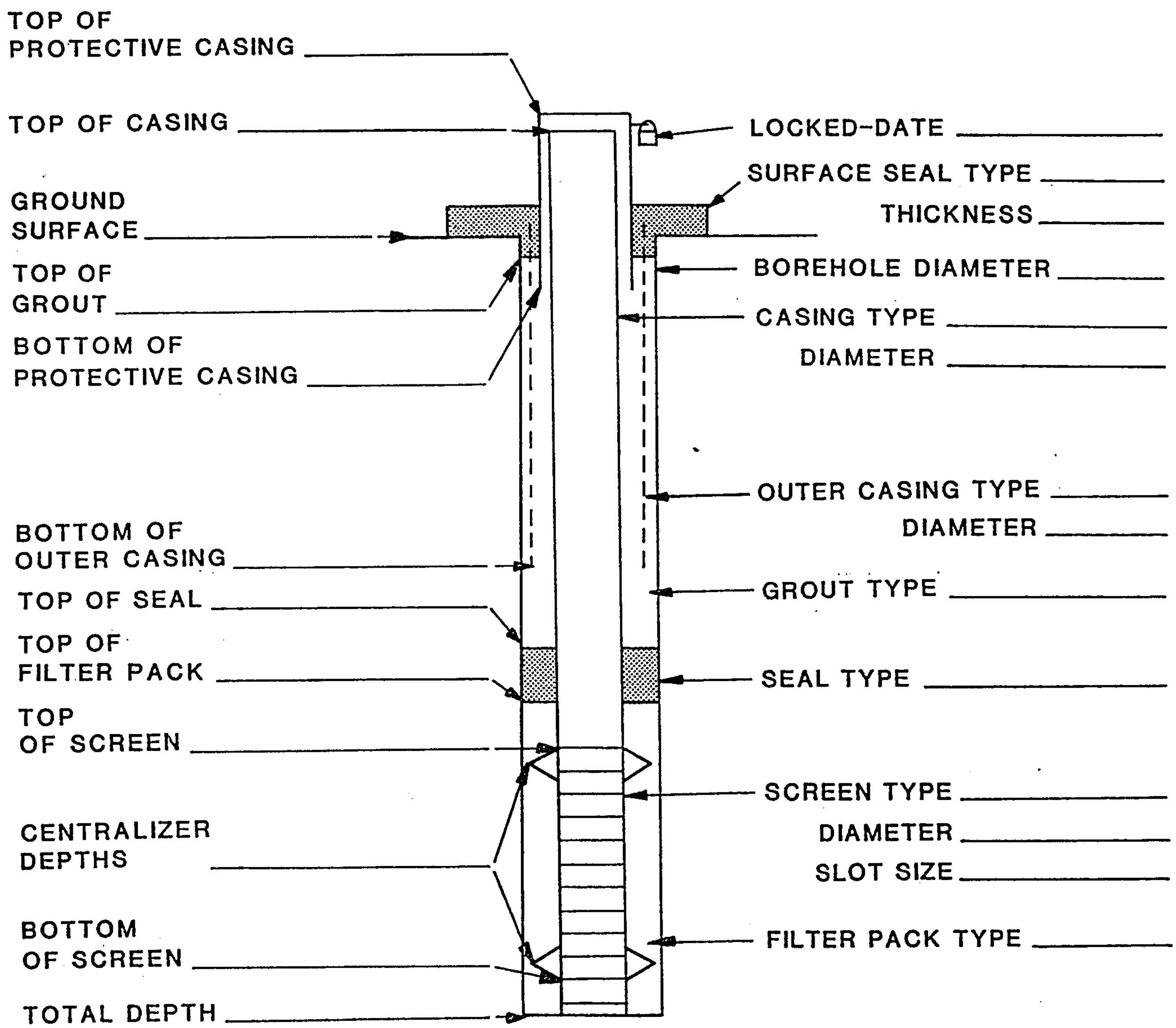
- Borehole diameter
- Casing dimensions and type

WELDON SPRING SITE REMEDIAL ACTION PROJECT

WELL COMPLETION RECORD

WELL NUMBER ________________________ DATE INSTALLED ____________________

PMC REPRESENTATIVE ____________________ DRILLER ________________________



COMMENTS ____

PMC REPRESENTATIVE SIGNATURE ________________________ DATE ____________

FIGURE 3-2: WSSRAP WELL COMPLETION RECORD

- Screen length and slot size
- Filter pack interval
- Seal details
- Grout type and interval
- Elevations (top of casing, ground surface)
- Stick-up of well casing above ground surface
- Protective casing details

3.3.3 Well Development

Well development entails surging, pumping, and/or bailing of wells in order to restore the natural hydraulic conductivity, remove foreign sediment and fluids introduced during drilling, and to assure collection of representative groundwater samples for water quality analyses.

A well development form (Figure 3-3) will be filled out upon completion of development for each well. The form will contain the following information:

- Water levels (static and final) measured to the nearest one-hundredth foot (0.01')
- Well depth measured to the nearest one-tenth foot (0.10')
- Well volume (casing and filter pack)
- Beginning and ending times recorded in a 24-hour clock format
- Description of water conditions (i.e., clarity, color, and description of sediments)
- pH
- Water temperature
- Specific conductance
- Comments (e.g. pumping rates, duration of surge and pump sequences, variations in flow/recharge rates, etc.)
- Total volume removed

WELDON SPRING SITE REMEDIAL ACTION PROJECT
WELL DEVELOPMENT FORM

PAGE ________ OF ________

WELL NUMBER ______________________________ DATE ______________

FIELD PERSONNEL ____

STATIC WATER LEVEL ________________ TOTAL DEPTH ______________

WELL VOLUME (CASING AND FILTER PACK) _________________________

DEVELOPMENT METHOD(S) ____

____

BEGINNING TIME ____________________________

INITIAL WATER CONDITIONS _____________________________________

____

____

RECHARGE RATE ____________________________

END TIME ____________________________

TOTAL VOLUME REMOVED ____________________ GALS.

TOTAL WELL VOLUMES REMOVED ________________ GALS.

FINAL TURBIDITY MEASUREMENT ________________ NTU

FINAL WATER LEVEL ________________ FINAL DEPTH ______________

COMMENTS ____

____

____

PMC REPRESENTATIVE SIGNATURE ____________________ DATE __________

FIGURE 3-3: WSSRAP WELL DEVELOPMENT FORM

- PMC Representative (field geologist or engineer) signature

The completed well development forms will be given to the project hydrogeologist or designee who will maintain a file on each monitoring well.

3.3.4 Sample Documentation

Standard sample handling and chain-of-custody documentation will be employed and maintained for all surface, vadose zone and groundwater samples collected for WSSRAP.

Sample documentation will include field data sheets (Figures 3-4 thru 3-6) and preprinted container labels (Figure 3-7).

The sampling team leader (WSSRAP environmental technican) will be responsible for all documentation. All documentation will be filled out with pens containing waterproof ink. The field data sheets will be completed at the time of sample collection. The field data form for groundwater sampling will include the following information:

- Monitoring well number/Sample number
- Date
- Sampling personnel
- Static water level
- Well volumes purged
- Water conditions
- Temperature
- pH
- Conductivity
- Time of sample collection
- Fractions collected

WELDON SPRING SITE REMEDIAL ACTION PROJECT (WSSRAP)
Route 2, Highway 94 South, St. Charles, MO 63303
Telephone (314) 441-8086 Telecopy (314) 447-0803

GROUNDWATER SAMPLING FIELD DATA FORM

WELL # ____________________ DATE: ______________

SAMPLE TYPE: R D FB JB DIB PERSONNEL: _________

____

TIME _________

_____ WELL SECURE YES NO TOTAL DEPTH __________________ FT.

_____ STATIC WATER LEVEL __________________ FT.

LENGTH OF WATER COLUMN __________________ FT.

DIAMETER OF WELL 2" 4" 6"
VOLUME OF WATER COLUMN
.16L FOR 2" .65L FOR 4" 1.5L FOR 6" ___________ GAL.

_____ BEGIN EVACUATION/RATE __________________

RATE OF RECHARGE V. SLOW SLOW MOD. FAST V. FAST

_____ NUMBER OF VOLUMES REMOVED: __________________

_____ TEMPERATURE __________________

pH __________________

CONDUCTIVITY __________________

WATER CONDITIONS ____________________________________

_____ COMPLETED SAMPLING

_____ TEMPERATURE __________________

pH __________________

CONDUCTIVITY __________________

_____ FINAL WATER LEVEL __________________ FT.

ANTECEDENT CONDITIONS:

FIGURE 3-4: WSSRAP GROUNDWATER SAMPLING FIELD DATA FORM

WELDON SPRING SITE REMEDIAL ACTION PROJECT (WSSRAP)
Route 2, Highway 94 South, St. Charles, MO 63303
Telephone (314) 441-8086 Telecopy (314) 447-0803

SURFACE WATER SAMPLING FORM

Sample Number: ____________

Location: ________________ Date: ______________

Personnel: ________________

____

Type of surface water: Lake Stream Outfall River Other ____

Flow Estimate: ____________

Method of Estimation: ______

Time ______

_____ Collect Sample Type: ____________________

_____ pH ____________

Temperature ____________

Conductivity ____________

Diagram:

FIGURE 3-5: WSSRAP SURFACE WATER SAMPLING FORM

WELDON SPRING SITE REMEIDAL ACTION PROJECT

SPRING AND SEEP WATER SAMPLING FIELD SHEET

Sample Number: ____________________

Location: ________________________ Date: __________

Sampling
Personnel: ______________________

____

Type of feature: Spring, wet weather, Seep, Other ______

Flow Estimate: ____________________________

Method of Estimation: _____________________

Time:

____ Collect Sample Type: ______________

____ pH ______________

Temperature ______________

Conductivity ______________

No. of Containers

1 gal plastic __________
1 gal amber __________
VOA vials __________
Other __________

____

Parameters ____

____

Field Filtered Yes ____ No ____

Field Preserved Yes ____ No ____

Diagram/Comments:

FIGURE 3-6: WSSRAP SPRING AND SEEP WATER SAMPLING FIELD SHEET

Weldon Spring Site Remedial Action Project (WSSRAP)
MK-FERGUSON COMPANY (PMC)
Rt. 2, Hwy 94, St. Charles, MO 63303
Phone (314) 441-8086
Sample Number:

Location: WSCP / WSRP / WSQ / WSVP
Parameter:
Matrix:
Collected By:
Date: Time:

Weldon Spring Site Remedial Action Project (WSSRAP)
MK-FERGUSON COMPANY (PMC)
Rt. 2, Hwy 94, St. Charles, MO 63303
Phone (314) 441-8086
Sample Number:

Location: WSCP / WSRP / WSQ / WSVP
Parameter:
Matrix:
Collected By:
Date: Time:

FIGURE 3-7: WSSRAP PREPRINTED LABEL FORMS

All original field data forms will be retained in the project files.

3.3.5 Sample Packaging, Labeling and Preservation

All samples will be transferred into the appropriate bottles (Table 2-3) with Teflon-lined caps. Bottles and caps are supplied and decontaminated prior to use by an approved laboratory. Each container will have a preprinted label. The label is marked with a unique serialized number and the parameter(s) to be analyzed are identified on it. After labeling, the sample containers will be placed on ice in a secured cooler.

All samples will be packaged, labeled and preserved according to standard U.S. EPA Region VII procedures and Department of Transportation regulations as required in 49CFR.

3.3.6 Chain-of-Custody

The WSSRAP standard Chain-of-Custody form (Figure 3-8) will accompany a sample or group of samples as custody of the sample(s) is transferred from the original custodian to subsequent custodians. The custody record will provide the necessary information to cross-reference the sample number to the specific sampling location and will provide the date of collection as well as documentation of custody. Detailed components and procedures are described in the Groundwater Sampling SOP (ES&H SOP #4.01.01). The samples obtained by the field sampling team will be picked up by a laboratory courier on a daily basis. The field sampling team will offer a completed chain-of-custody form for signature to the sample receiver and will retain a copy of the completed form. Chain-of-custody procedures are applied to all samples collected for site characterization as described in Section 6.0 of the QAPP. Copies

WELDON SPRING SITE REMEDIAL ACTION PROJECT (WSSRAP)
Route 2, Highway 94, St. Charles, MO 63303
Phone (314) 441-8086 Telex (314) 447-0803

ENVIRONMENTAL SAMPLE CHAIN OF CUSTODY FORM

WSSRAP Contact: ____________________ WSSRAP File NO.: ____________________
Phone Extension: ____________________ Date Samples: ____________________
Laboratory Receiving Samples: ____

Sample Number	No. of Containers	Description	Parameters	Turnaround Time Required

Samplers' Signatures: ____

Relinquished by:	Received By:	Date	Time	Reason for Transfer

Figure 3-8: WSSRAP ENVIRONMENTAL SAMPLE CHAIN OF CUSTODY FORM

of all chain-of-custody forms will be maintained in project files at WSS.

3.4 COMPUTER DATA BASE

A large amount of data will be generated during site characterization. Those field measurements and other data collected and analyzed during the hydrogeologic investigation will be reduced for input into the computerized data base maintained by the WSSRAP Environmental, Safety, and Health Department. The data will include logs, tracking forms, and results of laboratory analyses. Computer software is protected and documentable.

4.0 DATA ANALYSIS

4.1 INTRODUCTION

All data collection activities are in accordance with the Data Quality Objective (DQO) process as defined in EPA 540/G-87/003. The three-stage DQO process ensures that data collected are sufficient and of adequate quality for their intended uses. A major component in the Stage 1 DQO process will be the review and analysis of measurement data collected in the RI and those data collected during prior investigations.

A conceptual model has been constructed, with the utilization of existing data, in accordance with the Stage 1 DQO development process. This model, with known and potential sources, migration pathways, and receptors, has been described in Section 1.3 of this sampling plan. The Stage 1 process also recommends the delineation of specific objectives and goals of the investigative program. These are presented in Section 1.0.

Other sections in this plan address the subsequent stages of the DQO process. For example, Stage 2 components include:

- Delineation of specific objectives (Section 1.0)
- Identification of data uses and needs (Section 1.4)
- Identification of data quantity and quality needs (Section 2.0)
- Approach to sampling and analysis, including testing devices and procedures (Section 2.0 of this plan; WSSRAP and laboratory procedures manuals

Stage 3, the data collection process, is described in detail in Section 2.0.

Precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters are major considerations of the

DQO process for: reviewing and evaluating data (Stage 1); defining sampling options (Stage 2); and establishing goals for the Stage 3 data collection or sampling program.

Data adequacy, i.e. data validity and data sufficiency, then, is established after consideration of PARCC parameters. The quality of data is assured for PARCC by adherence to SOPs and utilizing external measures of quality. Data validation work tasks are considered by EPA to be a component of the sample analysis. EPA approved and/or best available methodology is used for data quality assessment.

Data collected under Stage 3 of the DQO process will be compiled, subjected to the Quality Assurance/Quality Control (QA/QC) element evaluations, incorporated initially into the conceptual model and ultimately to meet remedial action objectives of the study, into computer models. With the input of detailed chemical and physical hydrogeologic data, the models will allow for an evaluation of contaminant flow and transport mechanisms, and will permit a definition of the extent of contaminant plume migration as a function of time.

4.2 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) on the Weldon Spring project is in accordance with EPA guidelines and is defined as the total integrated program for assuring the reliability of monitoring data. Quality control (QC) is the routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process (U.S. EPA, 1980). The DQO process developed by EPA (March 1987) stipulates requirements for the preparation of a Quality Assurance Project Plan (QAPP). The process relies upon the incorporation of the 16 QA elements in the QAPP, Standard Operating Procedures (SOPs) and other documents, e.g., laboratory analytical methods and CLP procedures. Table 4-1 presents, in accordance with the DQO guidelines, the 16 QA elements and a reference to those documents that address QA issues which are applicable to this plan.

The DQO staged process has been addressed in the QAPP (Section 2.0). The overall objective of the data collection stage is to ensure that all data used to support decisions made by DOE meet the requirements imposed by federal and state agencies.

The quality assurance (QA) program is conducted for both routine environmental monitoring and characterization activities and is composed of two components: field and analytical QA evaluations.

The field QA program for field activities includes the following:

- Preparation of site-specific sampling plans and sampling procedures for collection of all environmental samples

- Annual audit of all field procedures with follow-up corrective action programs, if required

- Proper documentation of sample collection including sample collection forms, field notebooks and chain of custody records

- The routine collection and analysis of QC blanks including trip blanks and equipment blanks

The analytical QA program for laboratory analyses makes use of a number of different types of quality control samples to document the validity of the data generated. These samples include:

TABLE 4-1

QUALITY ASSURANCE PROJECT PLAN ELEMENTS AS RELATED TO WSSRAP HYDROGEOLOGIC INVESTIGATIONS SAMPLING PLAN (HISP)

QAPP Elements	Information Provided In
1. Title Page	HISP
2. Table of Contents	HISP
3. Project Description	QAPP
4. Project Organization and Responsibility	QAPP
5. Quality Assurance Objectives for Data Measurement	QAPP HISP
6. Sampling Procedures	SOPs HISP
7. Sample and Document Custody	HISP QAPP SOPs Analytical Methods/Detection Limits (Laboratory Procedures Manual)
8. Calibration Procedures	SOPs Analytical Methods/Detection Limits QAPP
9. Analytical Procedures	Analytical Methods/ Detection Limits
10. Data Reduction, Validation, and Reporting	HISP QAPP SOPs
11. Internal Quality Control	HISP QAPP SOPs Analytical Limits/ Detection Methods
12. Performance and System Audits	QAPP

TABLE 4-1 (cont.)

QUALITY ASSURANCE PROJECT PLAN ELEMENTS

QAPP Elements	Information Provided In
13. Preventive Maintenance	QAPP SOPs Analytical Limits/ Detection Methods
14. Specific Routine Measures Used to Assess Data Precision	SOPs HISP QAPP
15. Corrective Action	QAPP
16. Quality Assurance Reports to Management	QAPP

- <u>Method Blanks</u> (one per batch, batch not to exceed 20 samples). Method blanks contain all the reagents used in the preparation and analysis of samples to assess contamination rising from reagents, glassware and other materials used in the analysis.

- <u>Laboratory Control Samples/Spiked Blanks</u> (LCS - one per batch, batch not to exceed 20 samples). These samples are prepared by adding known quantities of compounds of interest to deionized water and are used to establish that an instrument or procedures were controlled.

- <u>Calibration Check Samples</u> (as needed, or per method). Calibration standards are periodically used to verify that the original calibration is still valid.

- <u>Duplicate and Spike Samples</u> (5% duplicate; 5% spike). Analysis of duplicate samples is performed to enable an estimate of the precision of the analytical procedures. Spike samples are measured to determine the accuracy of the analytical procedure and access matrix effects. For analyses conducted according to the Contract Laboratory Program (CLP) methodology, these controls are termed matrix spike and matrix spike duplicate samples.

- <u>Blind QC Samples</u> (one per 20 samples). Blind QC samples are inserted into the sample load in a fashion unrecognizable to the laboratory analyst. These samples, in addition to the standard duplicate sample analysis discussed above, are used to assess analytical precision.

- <u>EPA Laboratory Performance Evaluation (PE)</u> (Annually). In order to assess overall performance of the primary analytical laboratory, spike samples are submitted annually by EPA Region VII to the PMC primary laboratory.

- Interlaboratory Evaluation (Annually). In order to assess comparability of data, sample splits are shipped to different laboratories to provide a measure of analytical or method bias.

The specific monitoring activities include surface water and groundwater analyses for various organic, inorganic, and radioactive species.

These quality control measures are to assure that data collected from project sampling tasks are valid and meet the highest practical attainable level of precision and accuracy. These criteria, combined with the adherence to representativeness, completeness, and comparability requirements and guidelines (Section 4, QAPP) will allow for an accurate characterization of the site and the evaluation and delineation of remedial measures. The QA objectives for the hydrogeological characterization program will be met, in part, by the use of periodic audits of field sampling and laboratory analysis activities. The results of audits and technical quality control procedures, as well as other program QA documentation and reports described in this plan will be maintained to meet DOE and EPA requirements.

4.3 RI PLAN ELEMENTS

4.3.1 Groundwater Monitoring Well Network

Monitoring data gathered to date indicate the presence of a groundwater divide beneath the site. Sulfate, nitrate, nitroaromatics and uranium contaminant plumes have been identified. Data gathered in the future from monitoring wells will be used to refine the conceptual model, and the groundwater contour, contaminant plume, and isopleth maps of the WSS. Additional monitoring data will further define contaminant source and recharge areas and flow directions, and will delineate the extent of vertical and horizontal migration of contaminants.

4.3.2 Aquifer Testing

Data generated from the aquifer testing program described in Section 2.2 of this sampling plan will be analyzed by the use of commonly applied analytical formulae and computer programs. These data, displayed on a series of matching curves, graphs, tabulations and computer print-outs will be incorporated into conceptual and computer models, superimposed on or compared with groundwater contour and contaminant plume maps to determine the degree, extent, and impact of groundwater contamination. The data interpretation process will likely include the preparation of maps and cross-sections to depict anisotropy, zones of primary and secondary hydraulic conductivity, and other aquifer characteristics.

4.3.3 Bedrock Hydrogeology

Data gathered during the aquifer testing program will be expanded with the inclusion of hydrogeologic data gleaned from published geologic and environmental reports and maps from federal, state, and local agencies (e.g. USGS, MDNR, St. Charles County, and others) and from previous site studies. These data, and additional information gathered from planned soils, geological, geophysical, and hydrogeological investigations, will be reduced and compiled in the form of tabulations, maps, stratigraphic sections, cross-sections and drawings. These data will be used as additional components of the models to illustrate the extent and nature of fractures and jointing, weathering, structural and lithologic features, solution channels and other bedrock characteristics common to a karstic environment, and to define recharge and source areas.

4.3.4 Overburden Hydrogeology

This sampling plan describes the methods to be implemented to further characterize these zones. The vadose-zone monitoring operations in the overburden, sampling of soil for chemical and physical parameters, definition of perched groundwater zones, and soil attenuation studies will provide data which, upon analysis, will allow for the description of: 1) contaminant source areas; 2) the extent of overburden contamination migration routes; and 3) the rate of contaminant migration. Also the ultimate fate of contaminants can be predicted and possible remedial measures can be assessed. This characterization effort will also provide data for the determination of a suitable site for a disposal cell--a remedial action under consideration at the WSS.

4.3.5 Surface Water

Groundwater recharge and contaminant source studies coupled with a detailed hydrological and climatological study will provide data for conceptual and computer models. These models will allow for a better understanding of the water balance, description of surface water and contaminant flow from the site and area drainageways, and the identification of potential receptors of contaminants, e.g. Busch Wildlife Lakes, area ponds and streams, and springs and seeps resulting from the interaction of surface and groundwater flow mechanisms. Surface drainage features and facilities plotted on topographic and geologic maps will also allow for the consideration of ERA's (IRA's) to preclude further contaminant migration. Sludge and sediment samples collected from lakes, creeks and ponds can, upon analysis, provide a further understanding of source areas.

4.3.6 Other Analyses

Supplemental hydrogeological studies may include biological, chemical and geochemical, climatological and meteorological and other research or field studies necessary to fulfill the objectives of the RI. The DQO process provides a framework for data collection under the RI program and evaluation of data in accordance with Stage 1 DQO guidelines. The field data collection program delineated in Section 2.0 is intended to provide sufficient, valid hydrogeologic data to characterize the site and meet stated objectives.

4.4 DATA SYNTHESIS

All data analysis efforts are directed to the development and refinement of the site conceptual model. These data will include source characteristics, the nature and extent of contamination, contaminant migration and transport mechanisms, and environmental and health impact. In this process, quantitative results will be applied to the conceptual model.

The models, with accompanying maps, tabulations, cross-sections, graphs, logs and other back-up data will, in accordance with EPA's RI/FS guidelines, allow for the description of: 1) the environmental setting of the site, e.g., surface features, soils, geology, hydrology, meteorology, and ecology; 2) source location, types, quantities, and concentrations of contaminants; 3) the nature and extent of contamination; and 4) an analysis of contaminant fate and transport.

The type of models to be used will be ascertained upon receipt of data and after its incorporation into existing simplified models which will dictate the need for, and the selection of, more complex analytical or numerical models.

With the acquisition, analysis, and synthesis of additional data gathered under this and other work plans, the concurrent FS will proceed with the development and refinement of remedial measures in accordance with the phased RI/FS approach as mandated by CERCLA/SARA.

4.5 HYDROGEOLOGIC CHARACTERIZATION REPORTING

The results of analyses of the hydrogeologic data described above will be compiled into a report or reports, components of which can be extracted for the overall RI/FS-EIS process. Information from the hydrogeologic characterization study along with information from reports produced by the MDNR and the USGS will be incorporated into the site RI report.

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APPENDIX

TABLE A
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	LOCATION TYPE	LOCATION NAME	LOCATION DESCRIPTION	LATITUDE	LONGITUDE	APPROXIMATE ELEVATION (FEET MSL)
1	SP5101	Spring	Boys Town Camp Spring	About 1 mile south of Weldon Spring Heights; near the mouth of drainage 5100; flows from a concrete basin.	38^{O} 41'58"	90^{O} 40'58"	465
2	SP5102	Spring	West Tributary Junction Spring	In southeast draining branch of drainage 5100; just above mouth of east draining tributary about 1/4 mile upstream of Missouri River; spring rises from the bed or the creek.	38^{O} 41'14"	90^{O} 41'15"	470
3	SP5201	Spring	Rock Ledge Spring	About 1 mile south of Francis Howell High School and 3/4 mile upstream of the mouth of drain-age 5200; spring flows from bed-rock and cascades from a rock ledge.	38^{O} 41'09"	90^{O} 42'52"	490
4	SP5205	Spring	Peter's Spring	About 1/3 mile east-northeast of Weldon Spring Chemical Plant entrance; flows from west valley wall on top of alluvial terrace.	38^{O} 41'48"	90^{O} 43"'02"	565
5	SP5301	Spring	Highway 94 Spring	About 1/2 mile south of Weldon Spring Chemical Plant; flows from east side of drainage 5300 about 100 yards downstream of Hwy 94.	38^{O} 41' 23"	90^{O} 43'36"	570

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	LOCATION TYPE	LOCATION NAME	LOCATION DESCRIPTION	LATITUDE	LONGITUDE	APPROXIMATE ELEVATION (FEET MSL)
6	SP5303	Spring	Southeast Drainage Perennal Spring	About 1 mile south-southeast of Weldon Spring Chemical Plant; flows from east valley wall and across alluvial terrace via a 50 yard long spring branch.	38^{O} 41'03"	90^{O} 43'22"	520
7	SP5402	Spring	Natural Bridge Spring	About 1 mile south of Weldon Spring Chemical Plant; flows from east edge of valley 5400; spring branch is interrupted by a very small "natural bridge".	38^{O} 40'24"	90^{O} 43'51"	560
8	ST5401	Stream	Hamburg Quarry	About 1 1/2 miles south of Weldon Spring Chemical Plant; stream channel just below spring fed pond and upstream of quarry (just downstream of Springs SP5401 and SP5406).	38^{O} 40'27"	90^{O} 43'32"	475
9	SP5501	Spring	Deer Spring	About 1 1/2 miles south-southwest of Weldon Spring Chemical Plant; flows from creek bed adjacent to east valley wall; frequented by deer during dry times.	38^{O} 40'37"	90^{O} 44'24"	515
10	ST6001	Stream	Dardenne Creek	Dardenne Creek at bridge for Highways I-64, US 40, and US 61.	38^{O} 44'05"	90^{O} 44'23"	470

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	HORIZONTAL DISTANCE FROM SITE* (MILES)	VERTICAL DISTANCE FROM SITE* (FEET)	GRADIENT FROM SITE* (FT/MI)	ESTIMATED FLOW RATE (GPM) MAXIMUM	ESTIMATED FLOW RATE (GPM) MINIMUM	GEOLOGIC FORMATION	RATIONALE
6	SP5303	0.85	90	106	200+	1	Burlington Limestone	Perennial spring partially supplied by losing stream segment 300 to 500 yards up-stream; only perennial spring in drainage 5300.
7	SP5402	1.00	50	50	50+	?	Burlington Limestone	Closest moderate flow spring to the site in drainage 5400.
8	ST5401	1.50	135	90	200+	?	Fern Glen Formation (Limestone)	Combined flow of a large flow spring, a moderate flow spring, and moderate surface flow near the mouth of drainage 5400.
9	SP5501	1.45	95	66	200+	100+	Fern Glen Formation (Limestone)	Spring with largest flow in drainage 5500.
10	ST6001	2.75	140	51	Enormous	Large	Burlington Limestone	Combined surface water drainage and groundwater discharge from a large area north and west of site.

* Measured from the groundwater divide location at elevation 610 under Building 408.

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	HORIZONTAL DISTANCE FROM SITE* (MILES)	VERTICAL DISTANCE FROM SITE* (FEET)	GRADIENT FROM SITE* (FT/MI)	ESTIMATED FLOW RATE (GPM) MAXIMUM	MINIMUM	GEOLOGIC FORMATION	RATIONALE
1	SP5101	2.45	145	59	1000+	?	Burlington Limestone	Large flow perennial spring; major source of flow in drainage 5100.
2	SP5102	2.20	140	64	100+ to 200+	?	Burlington Limestone	Moderate flow spring; secondary source of flow in drainage 5100.
3	SP5201	0.95	120	126	200+	Nil	Burlington Limestone	Largest spring in drainage 5200; source of all flow in downstream half of drainage.
4	SP5205	0.55	45	82	5+	?	Burlington Limestone	Small to moderate flow spring; one of the closest springs to the site.
5	SP5301	0.40	40	100	100+	0	Burlington Limestone	Wet weather spring supplied by water lost into swallow hole about 200 yards upstream; one of the closest springs to the site.

* Measured from the groundwater divide location at elevation 610 under Building 408.

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	LOCATION TYPE	LOCATION NAME	LOCATION DESCRIPTION	LATITUDE	LONGITUDE	APPROXIMATE ELEVATION (FEET MSL)
11	SP6101	Spring	Weldon Spring	In village of Weldon Spring; spring flows from concrete basin along road ditch on south side of Highway 94.	38^{o} 42'47"	90^{o} 41'15"	520
12	ST6101	Stream	Crooked Creek	About 1/2 mile northwest of the village of Weldon Spring; at bridge on gravel road.	38^{o} 43'07"	90^{o} 41'52"	525
13	SP6201	Spring	Army Reserve Fence Spring	About 1/4 mile northwest of Ash Pond; spring flows from stream bed about 25 feet upstream of Army Reserve Fence.	38^{o} 42'11"	90^{o} 44'12"	585
14	ST6201	Stream	Lower Schote	At bridge over Schote Creek about 1 mile downstream of highways I-64, US 40 and US 61.	38^{o} 43'23"	90^{o} 42'22"	495
15	ST6202	Stream	Schote Creek at Frog Pond Branch	About 1/2 mile northeast of August A. Busch Wildlife Area Headquarters.	38^{o} 42'34"	90^{o} 44'00"	555
16	SP6301	Spring	Burgermeister Spring	About 1 to 1 1/2 miles north of the site; spring flows from concrete basin in alluvium of valley bottom; spring branch flows to Burgermeister Branch to the north.	38^{o} 43'02"	90^{o} 44'17"	532

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	HORIZONTAL DISTANCE FROM SITE* (MILES)	VERTICAL DISTANCE FROM SITE* (FEET)	GRADIENT FROM SITE* (FT/MI)	ESTIMATED FLOW RATE (GPM) MAXIMUM	ESTIMATED FLOW RATE (GPM) MINIMUM	GEOLOGIC FORMATION	RATIONALE
11	SP6101	2.45	90	37	100+	10	Burlington Limestone	Spring with the largest flow in drainage 6100.
12	ST6101	2.20	85	39	Large	0	Burlington Limestone	Combined surface water flow of fork of drainage 6100; no known springs in this fork of the drainage.
13	SP6201	0.70	25	36	10+	0	Burlington Limestone	Only known spring in drainage 6200; one of the closest springs in drainage 6200.
14	ST6201	2.10	115	55	Enormous	Nil	Burlington Limestone	Combined flow of drainage 6200; no significant springs in drainage 6200.
15	ST6202	1.00	55	55	Enormous	0	Burlington Limestone	Combined flow of upper portion of drainage 6200 (normally no flow); includes the normally small flow leaking from Lake 36 on Frog Pond Branch.
16	SP6301	1.60	78	49	2000+	30	Burlington Limestone	Largest spring known in drainage 6300; water tracing tests confirm connection from losing streams adjacent to the site to this spring site contaminants detected at this spring.

* Measured from the groundwater divide location at elevation 610 under Building 408.

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	LOCATION TYPE	LOCATION NAME	LOCATION DESCRIPTION	LATITUDE	LONGITUDE	APPROXIMATE ELEVATION (FEET MSL)
17	SP6303	Spring	Francis Howell Cemetery Wet Weather Spring	About 1 to 1 1/2 miles north-northwest of the site; about 100 feet upstream of Busch Wildlife Area Road C along Burgermeister Branch; on alluvial terrace at east valley wall.	38^{O} 42'59"	90^{O} 44'28"	544
18	SP6304	Spring	Francis Howell Cemetery Spring	About 1 to 1 1/2 miles north-northwest of the site; about 150 yards upstream of Busch Wildlife Area Road C along Burgermeister Branch; in streambed by large sycamore tree.	38^{O} 42'56"	90^{O} 44'29"	544
19	SP6306	Spring	Twin Island Lake Spring	At Twin Island Lake Camp; about 2 miles north of the site; flows from alluvium on west bank of Burgermeister Branch about halfway between Twin Island Lake and Highways I-64, US 40 and US 61.	38^{O} 43'43"	90^{O} 43'52"	485
20	SP6307	Spring	Rangeline Spring	Along Highways I-64, US 40, and US 61 just south of Dardenne Creek.	38^{O} 43'59"	90^{O} 44'15"	480
21	ST6301	Stream	Lower Burgermeister Branch	About 2 miles northwest of the village of Weldon Spring; at bridge on gravel road.	38^{O} 44'01"	90^{O} 43'19"	475

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	HORIZONTAL DISTANCE FROM SITE* (MILES)	VERTICAL DISTANCE FROM SITE* (FEET)	GRADIENT FROM SITE* (FT/MI)	ESTIMATED FLOW RATE (GPM) MAXIMUM	ESTIMATED FLOW RATE (GPM) MINIMUM	GEOLOGIC FORMATION	RATIONALE
17	SP6303	1.60	66	41	50+	0	Burlington Limestone	Water tracing tests confirm connection to this spring from losing streams adjacent to the site; contaminated by red water during World War II TNT production.
18	SP6304	1.55	66	43	50+	5-	Burlington Limestone	Contaminated by red water during World War II TNT Production.
19	SP6306	2.25	125	56	100+	?	Burlington Limestone	Water tracing test confirmed connection from swallow hole in Busch Wildlife Lake 35 to this spring; contaminated by red water during World War II TNT production.
20	SP6307	2.65	130	49	5+	?	Burlington Limestone	Small perennial spring discharging groundwater to Dardenne Creek; near area of most significant red water contamination from World War II TNT production.
21	ST6301	2.60	135	52	Large	?	Burlington Limestone	Combined flow of drainage 6300 (Burgermeister Branch).

* Measured from the groundwater divide location at elevation 610 under Building 408.

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	LOCATION TYPE	LOCATION NAME	LOCATION DESCRIPTION	LATITUDE	LONGITUDE	APPROXIMATE ELEVATION (FEET MSL)
22	ST6302	Stream	Lake 34 Spillway	About 2 miles north of site; entrance to drop-inlet spillway pipe.	38^{O} 43'34"	90^{O} 43'59"	520
23	SP6501	Spring	500-Ft Contour Spring	About 1/2 mile east of Busch Wildlife Area Lake 33 near Dardenne Creek; spring flows from streambed of short tributary to Dardenne Creek.	38^{O} 44'02"	90^{O} 45'10"	500
24	SP6502	Spring	511-Ft Contour Spring	About 1/2 mile southeast of Busch Wildlife Area Lake 33; flows from gravel streambed of drainage 6500; about 75 yards upstream of Busch Wildlife Area Road C.	38^{O} 43'46"	90^{O} 45'23"	511
25	SP6601	Spring	Fish Hatchery Spring	About 200 yards south of Busch Wildlife AREa Lake 33; feeds fish-rearing ponds.	38^{O} 43'47"	90^{O} 46'06"	521

TABLE A (CONTINUED)
WATER TRACING SAMPLE LOCATIONS

ITEM	SAMPLE NUMBER	HORIZONTAL DISTANCE FROM SITE* (MILES)	VERTICAL DISTANCE FROM SITE* (FEET)	GRADIENT FROM SITE* (FT/MI)	ESTIMATED FLOW RATE (GPM) MAXIMUM	ESTIMATED FLOW RATE (GPM) MINIMUM	GEOLOGIC FORMATION	RATIONALE
22	ST6302	2.10	90	43	Large	25 to 50	Burlington Limestone	Combined flow of upper part of drainage 6300 (Burgermesiter Branch); water tracing test confirmed connection from shallow hole in Busch Wildlife Lake 35 to Lake 34 (but not to Burgermeister Spring which is upstream of Lake 34); a large spring is rumored to be in the bottom of
23	SP6501	2.95	110	37	200+	50-	Burlington Limestone	Contaminated by red water from wastewater lagoon Number 1 during World War II TNT production.
24	SP6502	2.80	99	35	500+	?	Burlington Limestone	Water tracing test confirmed connection from losing stream segment about 1 mile upstream; combined flow of most of drainage 6500.
25	SP6601	3.25	89	27	200+	?	Burlington Limestone	Moderate to large flow spring in drainage 6600.

* Measured from the groundwater divide location at elevation 610 under Building 408.

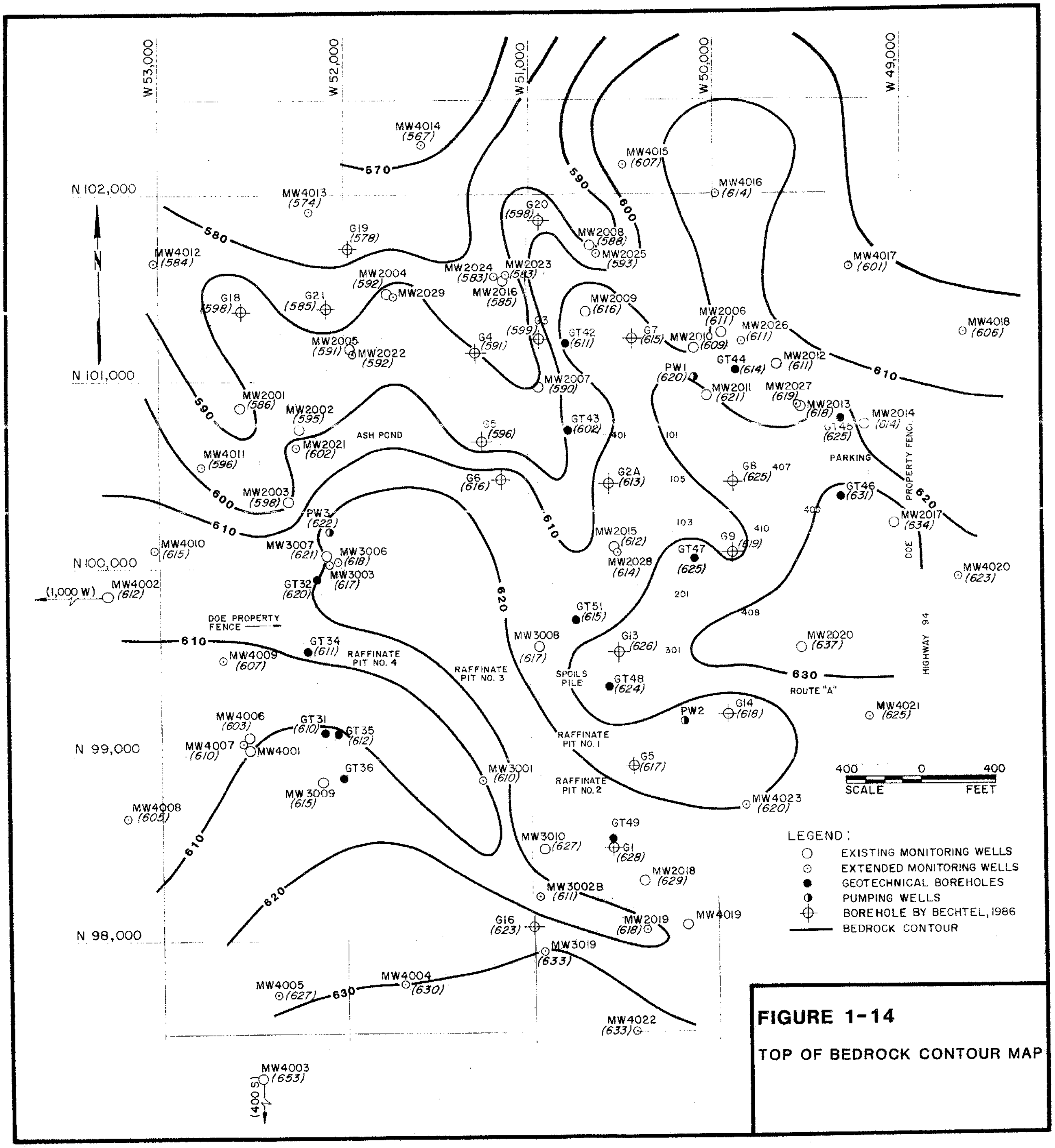

FIGURE 1-14

TOP OF BEDROCK CONTOUR MAP

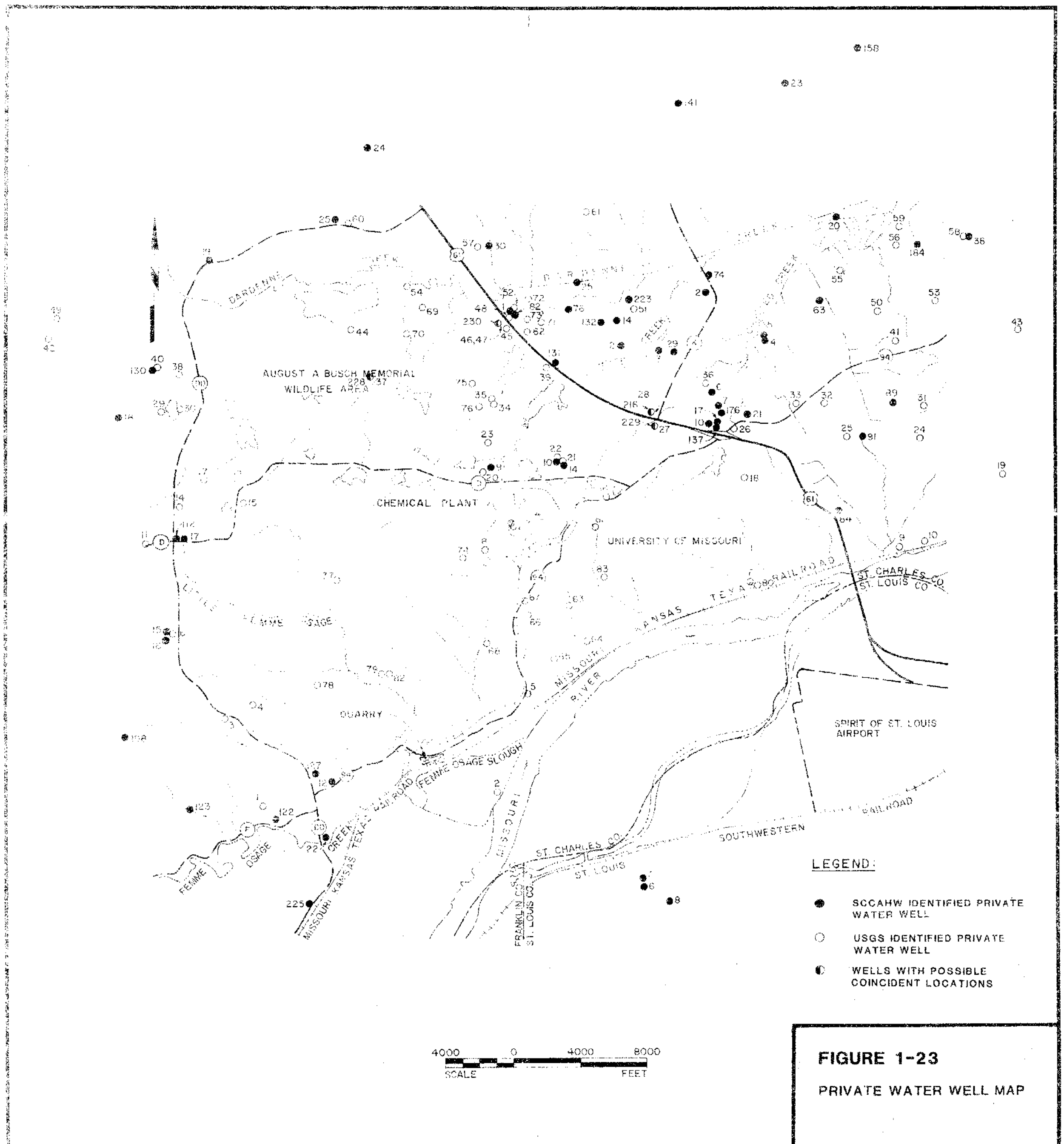

FIGURE 1-23

PRIVATE WATER WELL MAP

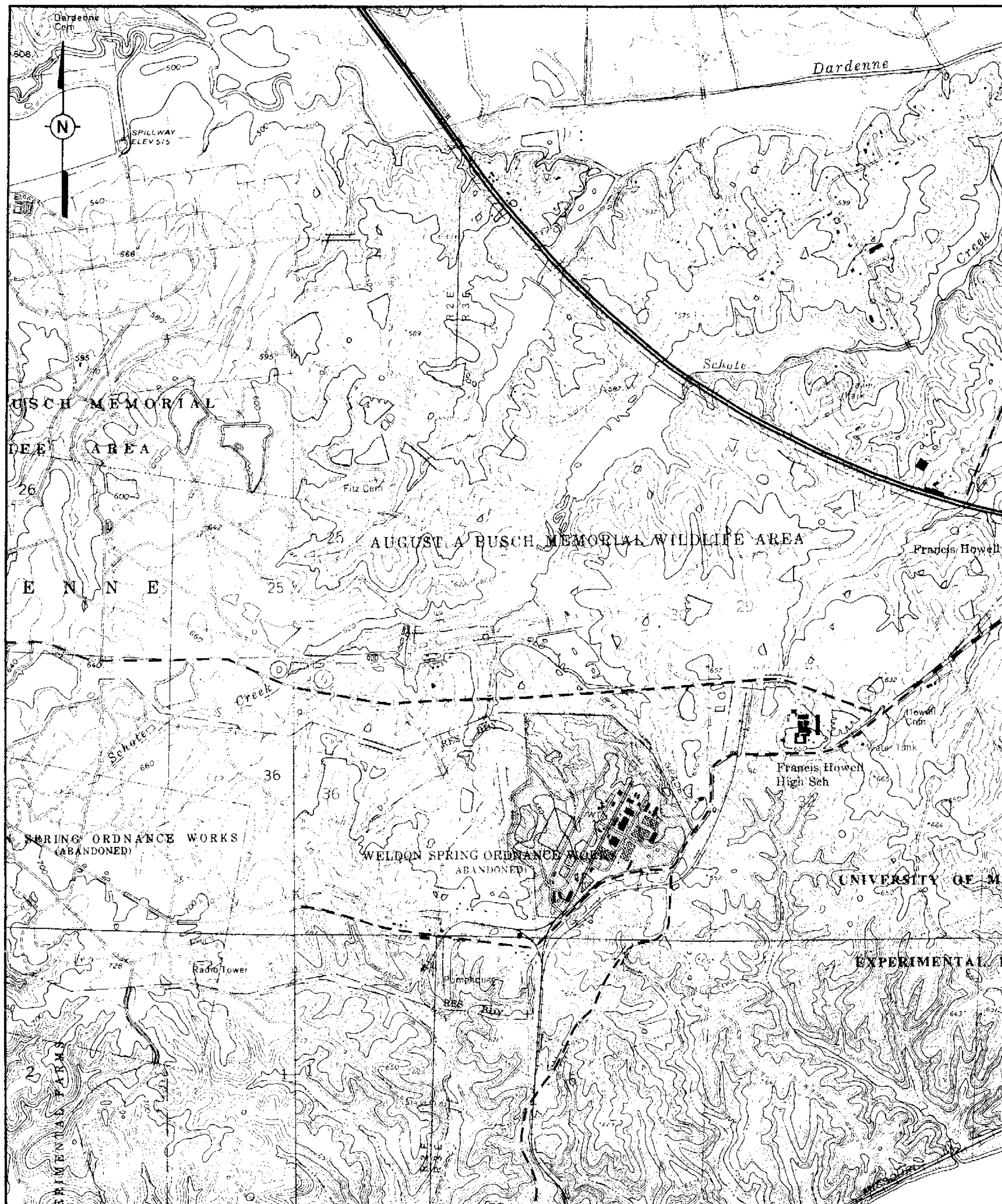

FIGURE 1-3

TOPOGRAPHIC MAP OF THE WELDON SPRING SITE AND SURROUNDING AREA

0 1000' 2000
SCALE

SOURCE: USGS

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